Comparing soil nematode composition in bluebunch wheatgrass *P. spicata* root to the occurrence of invasive plants *C. stoebe* and *L. dalmatica*

by

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Abstract

The viability of native bunchgrass ecosystems throughout the PPxh BEC subzone and in Kenna Cartwright Park (KCP) in Kamloops B.C. are under threat by invasive plants. Once established, invasive plants are difficult to eradicate and can predominate the landscape. I collected soil samples from a relatively undisturbed bunchgrass reference site composed of native bluebunch wheatgrass (*Pseudoroegneria spicata*), and I collected soil samples from a bunchgrass site occupied by the invasive plants, spotted knapweed (*Centaurea stoebe*) and dalmatian toadflax (*Linaria dalmatica*), to compare the soil nematode communities. My results reveal differences in the community-level biodiversity and abundance of soil nematodes between sites. The Maturity Index and the Plant Parasitic Index indicate that the native bunchgrass site had a "Structured" soil food web and that the site occupied by invasive plants had a "Basal" soil food web. My results indicate soil nematodes are useful as bioindicators of soil properties and these data provide useful criteria to help prioritize sites for ecological restoration.

Keywords: Nematology; invasive plants; *Pseudoroegneria spicata*; biological indicators; ecological restoration

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List of Acronyms

CP	Colonizer-Persister Index
EI	Enrichment Index
KCP	Kenna Cartwright Park
MI	Maturity Index
PPI	Plant Parasitic Index
PPN	Plant Parasitic Nematode
PPxh	Ponderosa pine/ bunchgrass very dry very hot
s.g.	Specific Gravity
SI	Structure Index

Glossary

Disturbance	Temporally discrete events that modify the biotic and/or abiotic components of the ecosystem.
Ecosystem Resilience	Capacity of an ecosystem to respond to disturbance without changing to a fundamentally different state.
Ecosystem Resistance	The abiotic or biotic ecosystem properties that remain unchanged when subject to disturbance.
Ecological Succession	The process of change in the species structure of an ecological community over time. Primary and Secondary types, “Alternate Stable States”.
Faunal Profile	A representation of the condition of a food web in relation to its structure and enrichment as indicated by weighted nematode community analysis.
Invasive Plants	A non-native, highly competitive species that is difficult to eradicate.
Soil Structure	The arrangement of the solid parts of the soil and of the pore space located between them. It is determined by how individual soil granules clump, bind together, and aggregate.

Introduction

The viability of bunchgrass ecosystems in B.C. are under threat from invasive plants and other effects compounded by over-exploitation and climate change (Wang et al. 2012). Invasive plants alter soil properties and ecosystem functions to facilitate establishment and are a threat to the viability of bunchgrass ecosystems (Reinhart and Callaway 2006, Jordan et al. 2008). Treatments to restore native plants and the natural vegetation structure should account for different responses from the plant community and different plant species. Eradication of invasive plants can be difficult because treatments might be costly, site-specific, and sites might require long-term management (Di Tomaso 2000, GCC 2017).

Once established, invasive plants can predominate the landscape and result in loss of the native plant community, and loss of the overall ecosystem biodiversity and ecosystem function (FAO 2014, GCC 2017). Bunchgrass plant communities provide ecosystem characteristics like forage for wild ungulates and nesting for birds (Hope et al. 1991, GCC 2017). Bluebunch wheatgrass (*P. spicata)* also provides ecosystem services including water filtration (Erskine and Rejmánek 2005) and erosion control (Lacey et al. 1989). Bunchgrass ecosystems can also be managed as areas of domestic grazing or public recreation.

The invasive plants spotted knapweed (*C. stoebe)* and dalmatian toadflax (*L. dalmatica)* are established and spreading in KCP (Tarasoff 2002, pers. obs. 2018). As the invasive plants spread, there is a corresponding loss of ecosystem functions and loss of native biodiversity in KCP. Furthermore, landscapes predominated by invasive plants rather than native bluebunch wheatgrass can result in an increased loss of topsoil (Lacey et al. 1989) and potential for trail closures due to erosion (City of Kamloops 2013). In a survey conducted by the City of Kamloops, a key reason the public visits KCP is for hiking, and nature viewing/ appreciation (City of Kamloops 2013). The extensive trail system in KCP enables hikers to experience the native bunchgrass ecosystem.

The City of Kamloops and the director of KCP have expressed interest in restoring the native bunchgrass ecosystem and managing invasive plants in KCP (City of Kamloops 2013, pers. conversation 2018). Provincial legislation like the *Weed Control*

Act and goals set by the City of Kamloops also provide incentive to manage invasive plants, and to limit transmission and establishment of invasive plants in B.C. (Province of BC 1996, City of Kamloops 2013). Restoring the natural environment and native biodiversity can maintain ecosystem services and further increase park appeal to the public. At this stage in restoring the bunchgrass plant community in KCP research is required to assess the current soil conditions and to identify and monitor the established plant communities. Invasive plant management can progress from simply treating the symptoms by only identifying areas where invasive plants are already established and begin to understand plant processes to develop management strategies.

A biologically diverse and abundant soil food web is generally an indicator of an ecologically resilient ecosystem (Brinkman et al. 2010, Andonian and Hierro 2011). To effectively manage invasive plants, one should understand above ground and below ground linkages because soil organisms, like nematodes, facilitate ecosystem functions in the soil food web including nutrient cycling and biological regulation of plants species (Bongers and Ferris 2001, Kardol and Wardle 2010). Plant community structure is closely tied to soil properties and understanding soil properties of a site provides criteria that can enable land managers to determine which areas are most likely to promote invasive plant establishment (Anderson 2003, Reinhart and Calloway 2006, Jordan et al. 2008, Mueller et al. 2018). Use of nematodes as bioindicators of soil properties are established in ecological restoration as bioindicators of soil properties to manage invasive plants (Verschoor 2002, Meiman et al. 2005, Andonian and Hierro 2010).

Nematodes as Indicators of Soil Properties

Nematodes are present in every ecosystem (Wardle et al. 1999), make up 80% of multicellular species, and are the most abundant metazoa on Earth (Bongers 2001). A nematode is any unsegmented worm of the phylum *Nematoda*, and has an elongated, cylindrical body and an exoskeleton called a cuticle (Yeates 2010). Nematodes can be used as bioindicators of disturbance of soil properties and food web structure by comparing the nematode community diversity and abundance in different sites (Wilson and Duarte 2009).

Nematodes are small enough to occupy the spaces between soil particles and are large enough to be identified with a light microscope. The structure of the nematode community reflects a snapshot of the current soil conditions and functions, such as the available nutrients and decomposition channels. Sequential assessment enables the analysis of soil degradation and ecosystem response to disturbance or enrichment (Bongers 1990, Kulmatiski and Beard 2010). Nematodes are useful as bioindicators of soil properties and functions because nematodes occur in high diversity and density in every soil type, react rapidly to disturbance, are easily isolated and identified, play a key role in soil food webs, and can easily be allocated to trophic groups (Bongers 1999, Bongers 2001).

Soil structure and available nutrients, and other soil properties and functions can be determined by analysing the nematode community present in the soil (Bongers 1990, Cesarz et al. 2015). Several established indices apply a weighted rank to the taxonomic diversity of the nematode community to asses' soil properties like food web structure, available nutrients, decomposition channels, and ecosystem response to disturbance or enrichment (Bongers 1990, Bongers 1999, Bongers and Ferris 2001). Biological indices including the Maturity Index (MI), the Enrichment Index (EI), the Structure Index (SI), and the Plant Parasite Index (PPI) have been developed to further describe soil properties and functions (Bongers and Ferris 2001, Cesarz et al. 2015).

A method to determine ecosystem response to a disturbance without complex chemical analysis is to use soil nematodes as bioindicators in tandem with an appropriate index. Some abiotic indicators of soil ecosystem response to invasive plant growth are established, like monitoring soil moisture, soil structure, or available soil nutrients like nitrogen and phosphorous (Kardol et al. 2010). However, the high cost of lab analysis may restrict data collection by limiting the number of soil samples one can afford to analyse. Rather than using complex chemical analysis of the soil, nematodes as bioindicators enable us to determine soil conditions in KCP and with further sequential assessment, nematodes can be used to determine the bunchgrass ecosystem response to invasive plant establishment. Specific nematode genera are associated with specific soil properties and functions (Bongers 2001, DeDeyn et al. 2004), and a range of soil properties and functions are linked to the established plant community (Reinhart and Calloway 2006, Jordan et al. 2008).

Nematode faunal composition analysis, also referred to as a biodiversity index, provides information on the food web structure, nutrients status, and functions of the soil

(Ettema and Bongers 1993). Several studies in similar grassland ecosystems have determined soil nematode diversity is correlated with soil functional parameters to serve as a bioindicator of soil functions (Ekschmitt et al. 2001, Neher 2001, Verschoor 2002). Furthermore, routine analysis of the nematode community enables rapid assessment of ecosystem response to disturbance or management treatments and provides criteria for effective soil enhancement and ecosystem restoration (Ettema and Bongers 1993, Erskine et al. 2005, Kulmatiski and Beard 2010). To properly apply nematodes as bioindicators to a site, the functions of the soil food web in relation to the plant species present must be adequately understood.

Many indices of biological diversity exist, several specific indices have been developed to analyse soil ecosystem properties and functions using soil nematodes. Colonizer-Persister rankings, or CP rankings, are used to construct indices, including the Maturity Index (MI) (Bongers 1990) and the Enrichment Index (EI) and Structure Index (SI) (Ferris et al. 2001). Bongers developed the Maturity Index for soil ecosystem analysis based on relative abundance of nematodes, categorized by life strategy, into a 1-5 Colonizer-Persister (CP) scale ranging from extreme r- strategists to extreme K-strategists. Building upon the Bongers model, Ferris et al. (2010) provided a framework for determining the enrichment (EI) and structure (SI) characteristics of food webs based on the CP scale, or the relative weighted abundance of different functional guilds of nematodes (Bongers 2001, Cesarz et al. 2015).

For example, using the CP scale, a bacterivorous nematode would be classified as a ‘Colonizer’ (generally r- strategists) and assigned a rank of 2. Another nematode species, like a nematode with predacious life strategy would be classified as a ‘Persister’ (generally K-strategists) and receive a rank of 4. Based on the ranking determined by the CP scale, the Enrichment index (EI) and Structure Index (SI) may be applied to categorize the soil food web as ‘Enriched’, ‘Structured’, or ‘Basal’. Ranking soil food webs using simple ratios of the weighted abundance of specific functional guilds provides useful indicators of food web structure, nutrient availability, and decomposition channels.

Two more indices can be applied to the CP scale. The Plant Parasitic Index, or PPI, is computed only for plant feeding nematodes with the rationale that their abundance is determined by the vigour of their host plants, which in turn is determined by ecosystem enrichment (Bongers and Ferris 2001, Wilson and Duarte 2009). The Maturity Index, or MI, is based on non-plant feeding taxa and considered a measure of environmental disturbance. Low MI values indicate a disturbed environment and high MI values indicate a stable environment (Bongers 1990, Bongers 1999). The PPI/ MI ratio is a sensitive indicator of enrichment in ecosystems and is lower under nutrient poor conditions and higher in enriched or stable conditions (Bongers and Ferris 2001, Griffiths et al. 2018).

Soil nematode biodiversity, applied to the appropriate index, are developed bioindicators used to determine soil properties, functions, and ecosystem response to a disturbance (Bongers and Ferris 2001, Andonian and Hierro 2011). Identification and classification of nematode species is useful to determine the effect of invasive plants *C. stoebe* and *L. dalmatica* have on soil properties in bunchgrass ecosystems (Griffin et al. 1996, Brinkman et al. 2010, Kulmatiski and Beard 2010, Cesarz et al. 2015). Several studies show both invasive plants *L. dalmatica* and *C. stoebe* alter soil conditions to facilitate establishment (Meiman et al. 2005, Jordan et al. 2008).

As restoration practitioners knowing general soil properties and the ecosystem response to invasive plant establishment will enable for prioritizing sites for treatment for invasive plants (Brinkman et al. 2010, D'Antonio and Chambers 2013). In KCP, the entire park cannot be treated simultaneously as some sites will have different treatment methods compared to other sites depending on several criteria including which invasive plants are established. Invasive plant management can progress from only treating areas where invasive plants are already established and begin to understand plant processes to develop management strategies. For example, in some grassland ecosystems Structured and Enriched soil food webs inhibit establishment of invasive plants compared to Basal soil food webs (Verschoor 2002, Jordan et al. 2008, Andonian and Hierro 2011). Also, in some sites invasive plants may not be easily observed or have low invasive plant occupancy, and other criteria can help determine if the site requires treatment, such as the soil food web diversity, soil structure, and soil enrichment levels.

Nematodes are useful in ecosystem restoration as bioindicators of food web structure and soil properties and functions; a pilot study to survey soil properties across KCP using nematodes as bioindicators is the first step to identifying the ecosystem response to invasive plant establishment. Once soil properties are determined and sites in KCP are prioritized for invasive plant treatment, restoration practitioners can efficiently control and prevent further establishment of invasive plants and enable long term management of the bunchgrass ecosystem in KCP and the PPxh subzone.

In KCP a site predominated with native plants and a site occupied by invasive plants were compared. In what is referred to as the enemy-free-hypothesis, the interaction between the soil biota and invasive plants may be mutualistic (Andonian and Hierro 2011). It is possible that invasive plants encounter less inhibitory effects of soil biota where they are introduced compared to the plants native range and conditions. Soil microbes, including nematode species, can promote or inhibit invasion (Meiman et al. 2005). If we understand these above ground-below ground linkages, soil biota can be used as bioindicators of ecosystem functions and soil properties (Kardol and Wardle 2010) to determine ecosystem response to invasive plant establishment.

Determining the soil properties in KCP in native bunchgrass sites and sites occupied by invasive plants can guide prioritizing areas for restoration and help identify areas where invasive plants are likely to establish. Once prioritized sites are identified, site-specific treatment efforts such as mowing, grazing, hand pulling, and prescribed fire can be applied (BC 2002, Jacobs 2006, GCC 2017, Hindley 2018).

My study established baseline data to create a faunal profile of the soil nematode community and determined soil properties in two sites in KCP. Using the faunal profile of the soil nematode community, the mean CP rank in each site was compared and the indices SI, EI, and MI/PPI were applied to further enable classification of soil properties. A park soil survey and monitoring plan can be implemented in KCP to assess the nematode community and classify the soil based on properties like soil food web structure, enrichment, and decomposition channels throughout the park. Ranking sites using the CP scale and applying the Maturity Index and Plant Parasitic Index is a method to use nematodes as bioindicators of ecosystem response to disturbance. With further data collection and monitoring, nematodes as bioindicators of ecosystem response to invasive plants can be applied to a landscape scale in KCP to identify sites to prioritize for ecological restoration.

Maintaining biodiversity and abundance of native soil biota is a long-term restoration goal, as a biodiverse native nematode population can enable restoration of the soil and the native bunchgrass ecosystem in KCP, as demonstrated in similar grassland ecosystems (Yuen 1966, Ekschmitt et al. 2001, Anderson 2003). Practicing ‘soil stewardship’ by facilitating the development of Structured or Enriched soil food webs will enable further ecosystem restoration by enabling Plant Parasitic Nematodes (PPN) to function in the potential role of affecting competition of plants species based on host-parasitic interactions (Andonian and Hierro 2011, D’Antonio and Chambers 2013). The effect of PPN on bunchgrass and invasive plants is lost if the plant parasites are considered as only part of an index, and ecological relationships are ignored.

A diverse and abundant soil nematode community also facilitates functions in the soil food web, including decomposition of organic matter, cycling of minerals and nutrients, sequestration of carbon, detoxification of pollutants, biological regulation of pest species, and modification of soil structure (Bongers and Ferris 2001). A biodiverse PPN soil food web classified as Structured or Enriched can enable growth of native bunchgrass and Basal soil food webs are demonstrated to facilitate establishment of invasive plants, including *C. stoebe* and *L. dalmatica* (Reinhart and Calloway 2006, Jordan et al. 2008).

Site Context: Kenna Cartwright Park

Kenna Cartwright Park, in Kamloops B.C., is categorized in the biogeoclimatic (BEC) subzone ponderosa pine very dry very hot (PPxh) indicating the ecosystem is predominantly composed of bluebunch wheatgrass *(Pseudoroegneria spicata)* and ponderosa pine (*Pinus ponderosa*). Typically, the bunch grass (BG) BEC zone forms at lower elevations compared to the ponderosa pine (PP) BEC zone, but the range of elevation in KCP creates a mosaic of PP and BG ecosystems. The very dry very hot PP subzone (PPxh) occurs from the valley bottom up to elevations of approximately 900 m (Hope et al. 1991). Bunch grasslands are considered a rare ecosystem in B.C. comprising of less than 1% of the province (CFCG 2018) and even though grasslands cover about 1.2 million ha of B.C. only 300,000 ha are classified as bunchgrass (GCC 2017). Bunchgrass ecosystems provide provincially unique ecological characteristics and ecosystem services.

Although the PPxh BEC subzone is one of the smallest subzones in B.C., the variety of grasses, shrubs, and open forest provide several unique ecological characteristics like forage for wild ungulates such as bighorn sheep (*Ovis canadensis)* and mule deer (*Odocoileus hemionus)*, and grazing for domestic stock (Hope et al. 1991, GCC 2017). Bunch grasslands also provide nesting areas, forage, and cover for several birds listed under the *Species at Risk Act* (SARA), including long-billed curlews (*Numenius americanus)* and sage grouse (*Centrocercus phaios)* (Krannitz and Rohner 1999, CDC 2019). The PPxh subzone also has suitable temperature and moisture regimes for a range of provincially endemic insects, amphibians and reptiles such as the tiger salamander *Ambystoma tigrinum*, and rubber boa *Charina bottae*.

Bunch grasslands also provide ecosystem services as areas of recreation for the public and as areas of grazing for domestic stock like sheep or cattle. Historically, bunch grasslands were intensely grazed and supported an economy of agriculture and ranching in B.C. (GCC 2017). Past grazing history has influenced bunchgrass ecosystems in the PPxh subzone and in B.C. and many hectares are dominated with weedy annual species from disturbance and prolonged misuse (Cummings et al. 2016, GCC 2017). Employing domestic grazing management practices to ensure proper use of the remaining bunchgrass is critical in this ecosystem. Other bunch grasslands like KCP or the Lac du Bois Grassland limit domestic grazing and are managed as popular areas for public recreation.

The majority of KCP is in the PPxh BEC subzone, classified as a very dry and very hot climate with ponderosa pine and bunchgrass as the predominant native vegetation (Hope et al. 1991). Several plant species identified in KCP are classified as provincially noxious under the *BC Weed Control Act*.

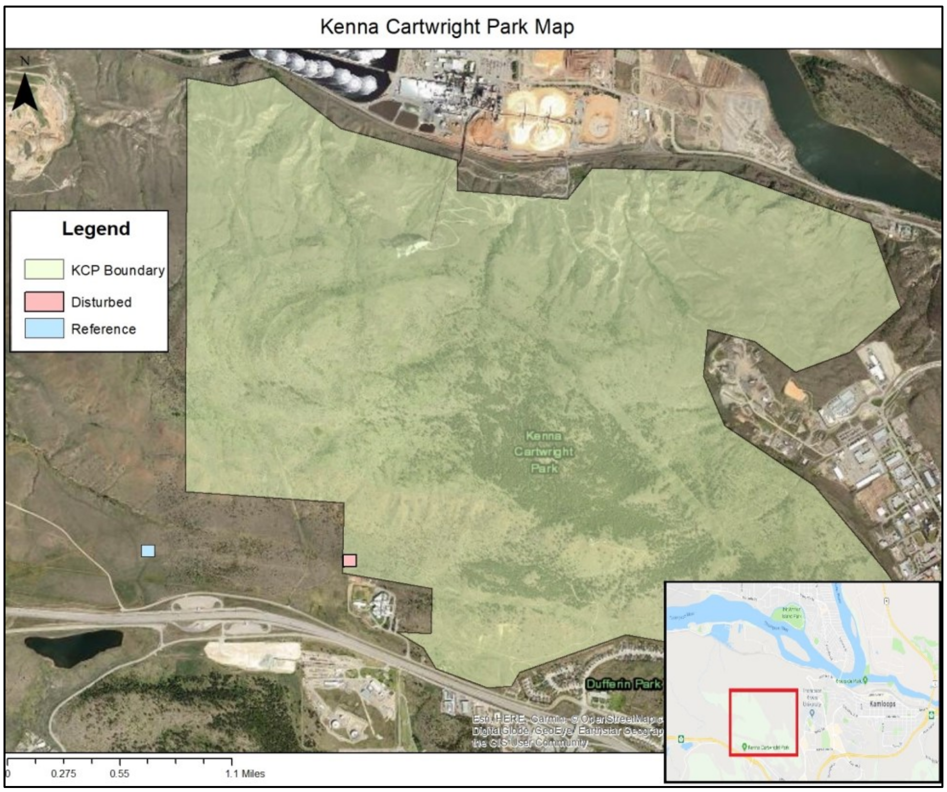

Figure 1. The boundary of Kenna Cartwright Park, west of the City of Kamloops, B.C. Study sites are indicated in red and blue. Kenna Cartwright Park is indicated by the red box in the inset map.

Established in 1996 KCP consists of a network of over 40 km of trails used for hiking and cycling in 800 ha around Mount Dufferin. As the largest municipal park in the province, the park experiences high year-round use. To prevent compaction and erosion of the trails from park users, the park has previously been closed during the spring snow melt (City of Kamloops 2013). Winter trail closure indicates the high use the trail system experiences, and that the trails may act as a vector for invasive plants to spread throughout the year.

Current Conditions

Climate

Some ponderosa pine (PP) and bunchgrass (BG) ecosystems are classified together under the PPxh biogeoclimatic zone designation. In the PPxh subzone mean annual precipitation is 280-500 mm, with 15-40% as snowfall. Summers are very warm; mean July temperature is 17-22°C. The hot, dry summers result in large moisture deficits during the growing season (Hope et al. 1991). In KCP the total annual precipitation of 344 mm in 2018 was higher compared to 2017 total annual precipitation of 200 mm. However, the total annual precipitation in 2018 is consistent with the 25-year average of 365 mm of precipitation annually in KCP, suggesting 2017 was a drier year than average (Environment and Climate Change Canada 2018).

The temperature ranges for each month from April to July 2018 are in the historical range of average monthly temperatures in KCP (DIP 2018, pers. obs. 2018). Despite a drier and warmer year in 2017, average annual precipitation and temperatures in 2018 indicate the soil cores extracted in this study were taken under average climate conditions.

Soil

Chernozem and Brunisol are the characteristic soil types in the park, Chernozems are associated with open grasslands and are characterized by a thick organic horizon close to the surface Ah layer. The Ah layer is formed through the decomposition of grasses and roots and is typically >10cm thick (Denton 1998). Brunisolic soils are associated with forested areas. Brunisols do not have large accumulations of organic matter because the plants in these areas do not produce as much vegetative litter as the grassland communities. Brunisols are also associated with areas of cooler temperatures because of shading by the forest. These cooler temperatures also inhibit decomposition of organic materials, Brunisols are referred to as ‘young soils’ as there has been little soil development from the original material. In general, Brunisols consist of a thin top organic layer and a thicker brown layer (Denton 1998).

Vegetation

Of the 800-ha of KCP, 505 ha has no presence of invasive plants. Approximately 291 ha in the park are infested with dalmatian toadflax, yellow toadflax, and spotted knapweed (Tarasoff 2002). A survey of the plant composition in KCP would likely show greater biomass and area predominated by invasive plants compared to 2001. In some areas, particularly on south facing aspects, invasive plants are established, and the site is intensely disturbed (>5 Invasive Plants/ m^2), (Tarasoff 2002, pers. obs. 2018). The landscape has been altered by fire suppression and stands of ponderosa pine are becoming more dense and encroaching on the bunch grasslands (Marrow 2016). Subsequently without an open forest canopy bluebunch wheatgrass is suppressed due to lack of sunlight from the ponderosa pine canopy (Carlier et al. 2009).

Outside of the ponderosa pine stands, much of the park ecosystem is predominated by the native plants big sage *Artemeisia tridentata* and bluebunch wheatgrass *P. spicata*. However, the southernmost part of the park, and the south aspect of Mt. Dufferin, are disturbed by invasive plants *C. stoebe* and *L. dalmatica* (Tarasoff 2002, pers. obs. 2018). There is potential for invasive plants to spread to unoccupied areas in KCP by the extensive trail network that passes through areas where invasive plants are already established. There are no endangered plants documented in KCP. Weed inventory mapping was available for Kenna Cartwright Park from 2001 (Figure 2).

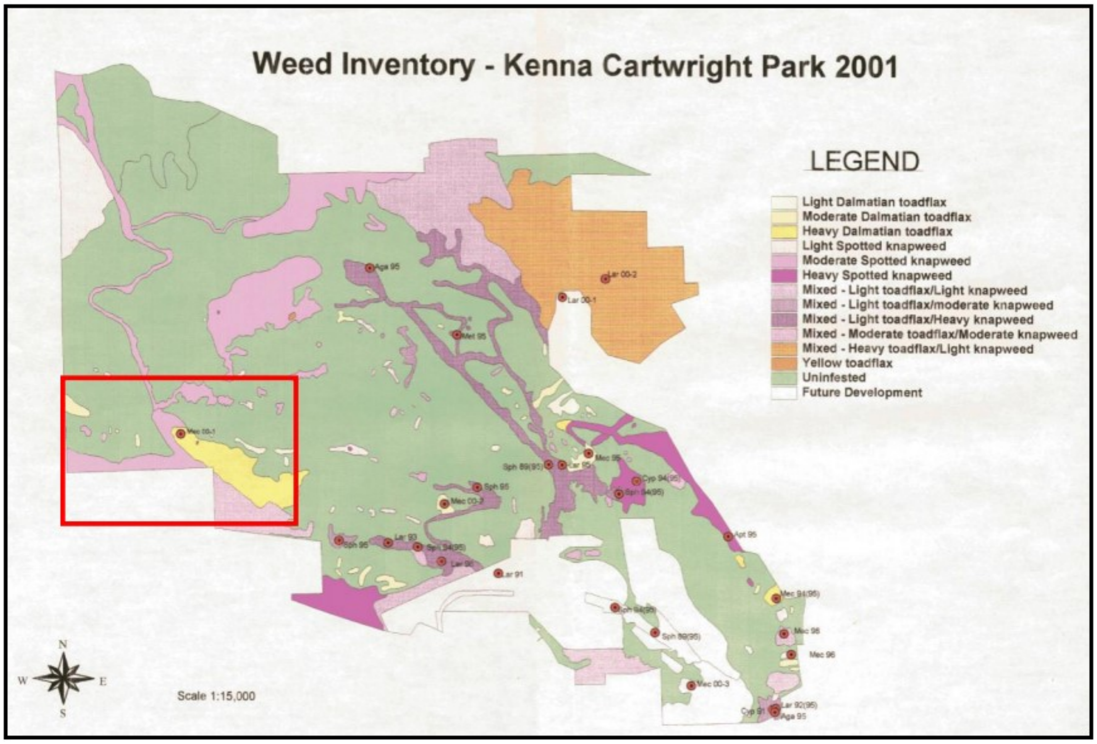

Figure 2. **Invasive plant inventory mapping from 2001 (Tarasoff 2002) indicating areas of high, moderate, and light infestation of *Centaurea stoebe* (spotted knapweed) and *Linaria dalmatica* (dalmation toadflax) in Kenna Cartwright Park. The red outline indicates my study area.**

Ecosystem Stressors

The bunchgrass community in KCP is under threat by several ecological stressors including invasive plant establishment, a history of fire suppression and over exploitation, and climate change (Tarasoff 2001, GCC 2017). Invasive plants can predominate the landscape and fundamentally change the ecosystem (FAO 2014). Some invasive plants create feedbacks that facilitate invasion (Kulmutaski 2010, Kuang 2015, Vandegehuchte et al. 2015) and invasive plant establishment is further enabled by climate change effects (Wang et al. 2012). In KCP and in the PPxh landscape, many bunchgrass and ponderosa pine ecosystems are threatened by a combination of fire suppression and drought, creating elements facilitating invasive plant establishment (Kuang 2015).

Invasive Plants

Invasive species can change the conditions of the ecosystem that native species previously existed in (GCC 2017). *Centaurea stoebe* has negative effects on bunchgrass ecosystem processes by altering forage and soil quality (Lacey et al. 1989, Erskine and Rejmánek 2005). *Centaurea stoebe* is a poor forage for ungulates because of the high fibre content and low nutrient content (Watson and Renney 1974) and *C. stoebe* grows into a dense over story, displacing native grasses with higher nutritional value (Watson and Renney 1974). *C. stoebe* can result in decreased grazing by wildlife and reduced fitness of animals (Krannitz and Rohner 1999, GCC 2017). Also, *Linaria dalmatica* is toxic for many ungulates (ISC 2014), therefore both invasive plants decrease forage in the bunchgrass ecosystem in KCP.

Centaurea stoebe and *L. dalmatica* affect the rate of erosion in bunchgrass ecosystems (Lacey et al. 1989). The amount of sediment yield from surface runoff is greater from stands composed of *C. stoebe* and *L. dalmatica* than stands composed of native bunchgrasses, resulting in increased erosion on sites dominated by *C. stoebe* and *L. dalmatica* (Lacey et al. 1989). The conversion of *P. spicata* bunchgrass to an ecosystem predominated by *C. stoebe* and *L. dalmatica* can increase the amount of sediment entering waterways and result in greater loss of topsoil (Lacey et al. 1989).

Bluebunch wheatgrass growth and establishment is adapted to a fire disturbance regime (Carlier et al. 2009) however due to fire suppression in many areas, including KCP, the historical fire disturbance regime has been altered, disrupting the natural growth of bluebunch wheatgrass. Even so, ecological relationships and appropriate treatments are becoming more understood and implemented as demonstrated by the City of Kamloops Trails Master Plan and Fire Management Plan (City of Kamloops 2013).

Fire Suppression

Historically bluebunch wheatgrass and ponderosa pine ecosystems in the PPxh subzone burned with low intensity fires as often as every 15-25 years (Hope et al. 1991). Before European settlement, Indigenous people used fire to remove brush for improving travel and attracting wild game to new growth (Reyes-Garcia et al. 2018). Because of this high frequency of burning, fires have played a necessary role in bunchgrass growth and developing forest structure in the PPxh subzone. For example, mature ponderosa pine trees have a thick bark that prevents low intensity fire from spreading to the crown (Pausas 2015). As the fire spreads through the understory, the grasses and new growth are burnt off leaving a relatively bare forest floor and restricting regeneration of new trees. This pattern has resulted in a mosaic of bunch grasslands and open stands of ponderosa pine across the landscape.

Currently in KCP, dense stands of ponderosa pine and Douglas-fir have begun to encroach on the grasslands (Tarasoff 2002, pers. obs. 2018). These dense clusters of trees can lead to an increased risk of arboreal disease and insect predation, and a decrease in tree health because of competition for water, nutrients, and light (Van Gunst et al. 2016). Use of fire to open the stands up enables for a more natural cycle of tree growth and facilitates growth and seed production of bluebunch wheatgrass (*P. spicata*) by increasing available sunlight and nutrients (Patton et al. 1988).

Fire is also a treatment for some invasive plants, including spotted knapweed *C. stoebe* if there are enough fine fuels to sustain intense fire to destroy the seed bank (Rice 2005). However, fire is not a catch all solution, as fire may promote growth of some invasive species such as *L. dalmatica* (Jacobs and Sheley 2003). One effect of fire suppression is a decrease of bluebunch wheatgrass emergent growth, and the lack of a fire disturbance facilitates establishment of invasive plants (Patton et al. 1988). Several prescribed burns have been implemented in KCP since 2005 with varying success.

A small prescribed burn was done in KCP in 2005 and in 2013, and a 7-ha burn in 2015, but most of the park still maintains a high fuel load and dense canopy for a PPxh ecosystem. (Marrow 2016, pers. obs. 2018). In the mid 2000's the mountain pine beetle epidemic went through KCP, killing 90% of the pines in the park (City of Kamloops 2013). These pines have since dried out and fallen, resulting in an increased fuel load in the park. In the past decade as a result of fire suppression, dense stands of ponderosa pines have replaced some of the open stands and bunch grasslands. These dense stands of ponderosa pine contain 'ladder fuels' that will result in hotter, more intense crown fires in the future.

Because there are residential areas and structures near KCP and in the PPxh subzone, many private residences are at risk from wildfires or fires caused by humans.

By performing a prescribed burn, fuel loading and ladder fuels can be reduced, greatly reducing the potential for urban interface fires. High intensity fire results in high severity burns to the soil and plants, which is more destructive to plants and soil structure compared to low intensity fire which facilitates *P. spicata* and *P. ponderosa* growth and reproduction (Saab et al. 2006). However, in some sites high intensity fire may be applied to eliminate the seedbed of invasive plants (Rice 2005). Photos of high fuels loads in KCP are shown in Appendix I, Figure A1.

Over Exploitation

Another factor that may affect establishment of *L. dalmatica* and *C. stoebe* is over exploitation from public recreation and past grazing practices. KCP is a popular destination for hiking and biking on the extensive trail system, however the network of trails can enable erosion and act as a vector for spread and establishment of invasive plants across the park. Seeds from invasive plants may be distributed by animals, shoes, bicycles and vehicles (Wallace 1968, Tarasoff 2002, Sheley and Krueger-Mangold 2003).

Historical grazing practices left much of the bunchgrass ecosystems in B.C. degraded and predominated by annual plants species or invasive plants (Cummings et al. 2016, GCC 2017). Even after grazing practices have stopped in KCP, it is unlikely there are many undisturbed bluebunch wheatgrass *P. spicata* ‘reference’ sites remaining in the park.

Climate Change

Temperatures and precipitation levels April - July 2018 are constant compared to the 25-year average (DIP 2018). Although annual precipitation levels are within the average historical range, climate change might affect KCP because rainfall precipitation has increased and winter snowpack levels have decreased over the last 25 years, and winter snow pack now melts earlier in the year (DIP 2018). Bluebunch wheatgrass is dependent on snowpack in January and February for growth in the spring (Volenec and Belovsky 2018). Climate change is most influential in the PPxh subzone by effecting the natural fire regime, such as drier temperatures enabling increased pine beetle epidemics creating drier fuels loads and facilitating more intense and damaging fires (Patton et al.

1988, Wang et al. 2012). Climate change may also alter plant community composition; thus, indirectly altering the soil communities that depend on their inputs.

Project Goals

Goal 1: Estimate nematode abundance in soils in Kenna Cartwright Park and the PPxh subzone.

Objective 1.1 Sample soil in representative sites (native bunchgrass site and site occupied by invasive plants) in Kenna Cartwright Park.

Goal 2: Determine nematode functional group composition in Kenna Cartwright Park and PPxh ecosystem soil communities.

Objective 2.1 Extract the representative nematode population from soil samples and identify nematodes to genus.

Objective 2.2 Categorize nematode functional groups, or genera, into CP scale and apply indices SI, EI and PPI/MI.

Goal 3: Determine basic seasonal abiotic effects on the soil on site.

Objective 3.1 Measure changes in soil moisture, soil pH, and soil temperature from April to July.

Goal 4: Design a pilot survey of KCP to determine soil properties and prioritize locations for invasive plant management treatments.

Objective 4.1 Create a key to effectively identify and index the nematode community present in KCP to compare the native bunchgrass site to the site occupied by invasive plants.

Objective 4.2 Provide treatment recommendations for sites occupied by invasive plants *C. stoebe* and *L. dalmatica*.

Methods

My study compared two sites in KCP to collect baseline data on nematodes as bioindicators of soil properties. I collected samples of the root mass and surrounding soil of bluebunch wheatgrass once per month from April - July from a representative 1-ha plot of relatively undisturbed ponderosa pine/ bluebunch wheatgrass ecosystem, PPxh BEC subzone (Hope et al. 1991). I also sampled soil cores in another 1-ha site located in KCP and in the PPxh subzone, with a presence of invasive plants spotted knapweed (*C. stoebe)* and dalmatian toadflax (*L. dalmatica)*. I sampled 10 soil cores in each 1-ha site along 100 m transects systematically placed every 20 m and I sampled soil cores at random points on the transects at least 5 m apart. This field sampling design was based on methods further described in Van Bezooijen (2006).

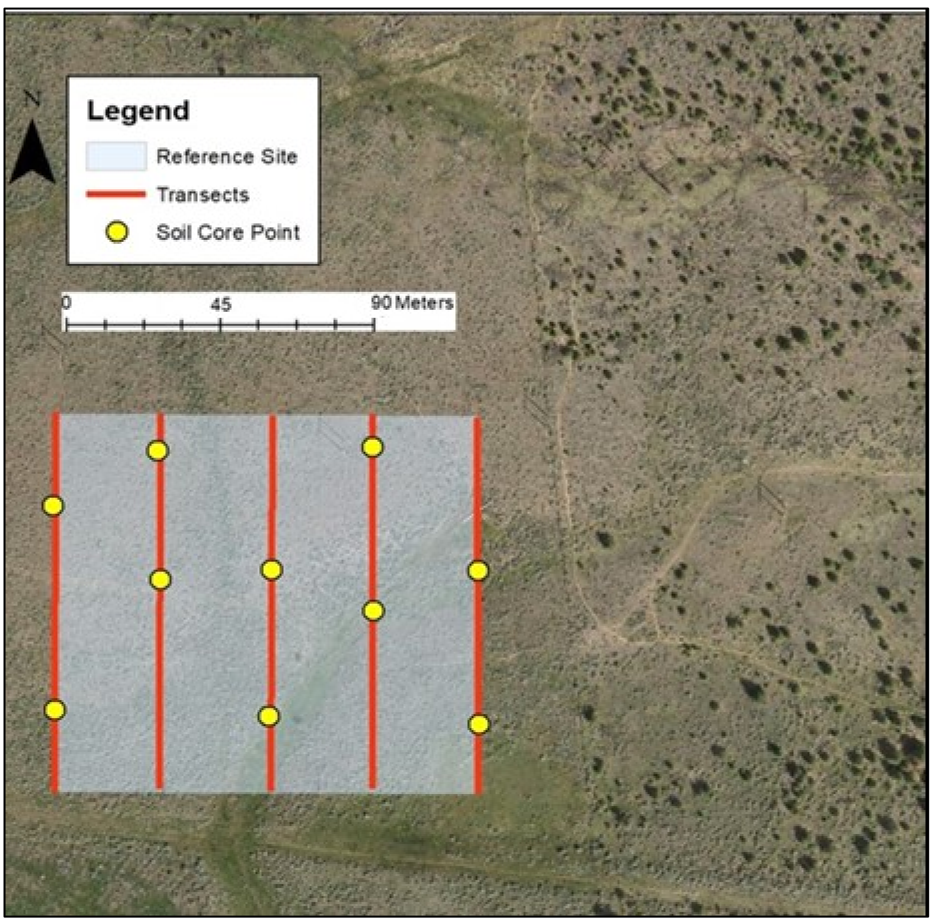

Figure 3. The study area and sampling design of the bluebunch wheatgrass *P. spicata* reference site. Located west of Kenna Cartwright Park, Kamloops B.C.

One of the biggest challenges for sampling soil nematodes is that, like many organisms, nematodes exhibit clumped distributions (Van Bezooijen 2006). Many physical and biological factors affect nematode distribution, such as high numbers of bacterivorous nematodes in a dung heap, or a localized infestation of plant parasitic nematodes near an infected root mass. The systematic sampling design accounted for this clumped distribution by sampling at random points at least 5m apart on the transect which was enough space to accurately survey the area and not subsample in the 'range' of each nematode community present.

Spatial variation refers not only to horizontal distribution but also to vertical distribution of nematodes. Depending on root growth, soil texture, and nematode species, nematodes can exist below 5 m. Generally, most nematodes can be observed in the upper 0 - 25 cm of the soil, in the area where the bulk of plant roots are located (Norton 1979, De Deyn et al. 2004). Other nematode species are present at greater depth; however, these species were likely not plant parasitic or did not directly interact with above ground processes and were not relevant to this study (Yeates 2010).

I drilled soil cores 25 cm deep and <5 cm from the root mass of bluebunch wheatgrass to sample the plant parasitic nematode community. After coring and bagging a soil sample, I used a soil probe to monitor soil abiotic factors in the soil pit. I monitored soil abiotic factors including soil volumetric moisture content (VMC), soil temperature, and soil pH levels in each soil pit from April - July. Each month I extracted 10 soil cores from both sites, or 20 soil cores extracted each month. In total I extracted 80 soil cores April – July 2018. One soil core was not suitable to use because of a broken bag therefore in statistical analysis N=79.

I determined the nematode community abundance and diversity present in the soil ecosystem. I quantified and monitored nematode abundance and species composition for each site. The degree of accuracy of identification for this study to establish biodiversity of a nematode population requires more accurate morphological identification compared to a qualitative study such as a diagnosis of a plant disease or a study of the nematode trophic guilds present, as rare PPN genera need to be included and identified in this study. To account for species interactions and to ensure rare species are counted in the study, each nematode observed was identified to family and if possible, identified to genera.

I extracted nematodes from the soil samples using the centrifugal floatation method. This method is the main method that enables isolation of active, slow-moving, and inactive nematodes (Forge and Kimpinski 2006). The method is based on differences in specific gravity (s.g.) between nematodes and other particles in a sample. In an extraction fluid with higher s.g. compared to nematodes, nematodes float. Particles with higher s.g. compared to the fluid will sink and the separation process is accelerated by centrifugation. The methods used in this study to extract nematodes with centrifugal flotation are described in detail by Van Bezooijen (2006) and by Forge and Kimpinski (2006).

Once extracted from the soil, I used light microscopy at magnification 400x to count observed nematodes and identify nematodes to community groups.I analysed the nematode sample by pipetting the sample onto a gridded counting tray and identifying nematode species by morphologic features using standardized methods described in Forge and Kimpinski (2006). If a nematode observed could not be identified to family, I photographed the unknown species and catalogued it for later identification.

I applied a weighted rank to each nematode functional group I observed (such as bacterivores, fungivores, or predacious) by applying the CP scale. The average CP levels of both sites were compared with Welch two sample t-tests (Figure 4). I increased the resolution of the nematode community analysis by applying the indices SI, EI, and PPI/MI, to compare site differences in soil structure and enrichment (Figure 5). I analysed soil abiotic factors with linear regression. I analysed the soil nematode community based on methods described in (Neher 2001, Brinkman et al. 2010, Griffiths 2018).

All indices applied in my study are based on a CP rank, or the weighted proportion of nematodes in the community that meet the index criteria. A general formula for calculating an index of a nematode family is described by (Bongers and Ferris 2001, Wilson and Duarte 2009). Where *XI* is the index of interest, v_i is the colonizer-persister (CP) value assigned to taxon *i*, and n_i is the number of nematodes in each of the taxa, *f,* that meet the criteria of the index.

$$XI = \sum_{i=1,f} v_i n_i \Big/ \sum_{i=1,f} n_i$$

Each nematode species is assigned a CP rank based on its functional guild, or life strategy; each nematode genus identified in this study had a CP value previously determined in other studies (Ettema and Bongers 1993, Bongers 1998, Kardol et al. 2010).

Table 1. Nematode genera and established Colonizer-Persister rank observed in Kenna Cartwright Park, Kamloops B.C. April-July 2018. CP ranks 1 and 2 indicate a Basal soil food web and CP ranks 3-5 indicate Structured and Enriched soil food webs.

Nematode Genera	CP rank
Rhabditis	1
Acrobeles	2
Cervidellus	2
Aphelenchus	2
Paratylenchus	2
Chiloplacus	2
Criconematidae	3
Dorylaimellus	3
Tylencholaimus	5
Aporcelaimidae	5
Longidoridae	5
Pungentus	5

Taxa within a CP class are similar in their responses to disturbance (Bongers 2001). An increase in 'colonizer' nematode abundance indicates stressed conditions such as a decrease in available soil nutrients in the soil food web (Bongers 1999). A food web that has been diminished due to stress or disturbance is described as 'Basal'. The most abundant nematodes in 'Basal' soil are ranked as CP-1 and CP-2. CP classes 1 and 2 are adapted to stressed conditions and are more tolerant of disturbance. Basal food web structure is predominated by nematode bacterial scavengers such as *Acroboloidies* and fungal feeders such as *Aphelechidae.*

A 'Structured' soil food web is described as when resources are more abundant or when recovery from stress is occurring, and more trophic links exist compared to a 'Basal' soil structure (Bongers 2001). A 'Structured' food web is predominately composed of nematodes with CP rank 3-4. The nematodes in this guild are susceptible to soil disturbance are often absent from disturbed or polluted environments.

The Structural Index (SI) is a measure of the number of trophic layers and potential for regulation of opportunists (bacteria feeders and/or plant parasitic nematodes), and the Enrichment Index (EI) is a measure of resource availability (Bongers and Ferris 2001, Neher 2001). I applied the PPI/MI ratio using methods described in Bongers (1999) and Bongers and Ferris (2001) to compare the nematode community in both sites with greater resolution (Table 2).

The null hypothesis of this study is that nematode populations do not have a significantly different mean 'Colonizer-Persister' rank (weighted measure of diversity and abundance) in the native bunchgrass reference site compared to the site occupied by invasive plants, or Ho: $\mu 1 = \mu 2$.

Let $\mu 1$ = mean CP rank for the native bunchgrass reference site. Let $\mu 2$ = mean CP rank for the site occupied by invasive plants.

The alternative hypothesis of my study is that nematode populations have a significantly different mean 'Colonizer-Persister' rank (weighted measure of diversity and abundance) in the native bunchgrass reference site compared to the site occupied by invasive plants, or H_A: $\mu 1 \neq \mu 2$.

Statistical Analysis

I analysed all results using R software (R core team 2018). I analysed soil abiotic factors using linear regression and Welch two sample t-tests. I compared the overall nematode community biodiversity between sites with linear regression. I compared the average CP rank of the nematode community in both sites using a Welch two sample t-test and calculated the variance using a 95% confidence interval. I rejected the null hypothesis, meaning the average CP rank between the native bunchgrass site and the site occupied by invasive plants is significantly different, or the true difference in means is not equal, (Figure 4). I determined the Maturity Index and Plant Parasitic Index by applying the established formulas to nematode abundance and diversity data using R software (R core team 2018). Using R software (R core team 2018) I computed a Pearson product-moment correlation to assess the relationship between soil moisture and soil temperature in both study sites.

Results

I conducted a Welch two sample t-test to compare the mean 'Colonizer-Persister' rank between a site occupied by invasive plants and a site predominated by native plants. There was a significant difference in the mean CP rank for a site occupied by invasive plants ($M = 2.8$, $SD = 0.183$) and the site predominated by native plants ($M = 3.6$, $SD = 0.206$); $t(79) = -12.42$, $p = 2.2\ e^{-16}$.

My data indicate that the mean 'Colonizer-Persister' rank differed between sites with native and invasive plants. The null hypothesis that nematode populations do not have a significantly different mean 'Colonizer-Persister' rank in the native bunchgrass reference site compared to the site occupied by invasive plants was tested and results show the null hypothesis was not supported, and the differences in the mean CP rank was statistically significant between sites.

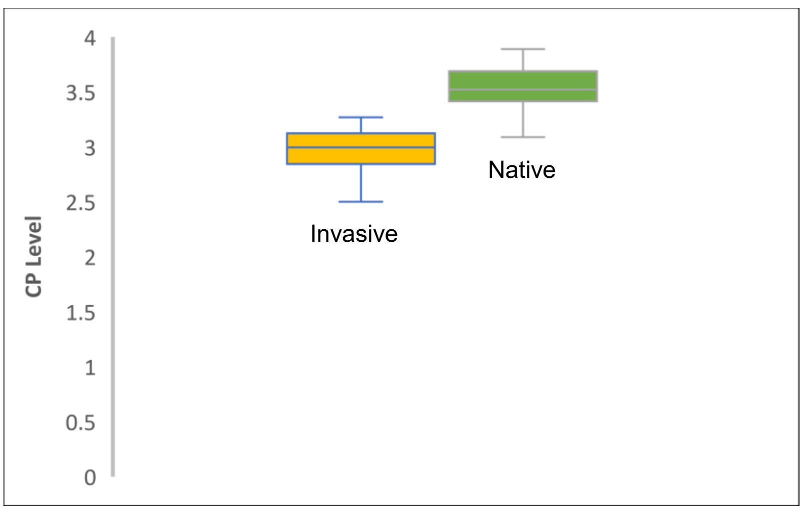

Figure 4. **Colonizer-Persister levels in a site occupied by invasive plants in yellow, M=2.8, and of a site predominated by native plants in green, M=3.6. N= 79. Both sites are near Kenna Cartwright Park in Kamloops, B.C.**

The nematode communities in the site occupied by invasive plants were predominated by 'Colonizer' type nematode species. Comparatively, the native bunchgrass site had a similar abundance of nematodes, but nematode diversity was higher than sites occupied by invasive plants. Furthermore, nematode communities in native bunchgrass site were predominated by 'Persister' type nematode species.

The samples extracted and analysed from the site occupied by invasive plants contained a nematode community with a mean CP of 2.8 which is considered a 'Basal' soil food web. The samples extracted and analysed from the native bluebunch wheatgrass site contain a nematode community with average CP of 3.6 which is considered a 'Structured' soil food web. No sites in KCP were classified as 'Enriched' in this study.

Applying the EI and SI indices, the site occupied by invasive plants is shown to have Basal soil structure SI= 35.0 and low Enrichment EI= 6.2 and the site predominated by native bunchgrass was shown to have Structured soil structure SI= 66.0 and low Enrichment EI= 13.6 (Figure 5).

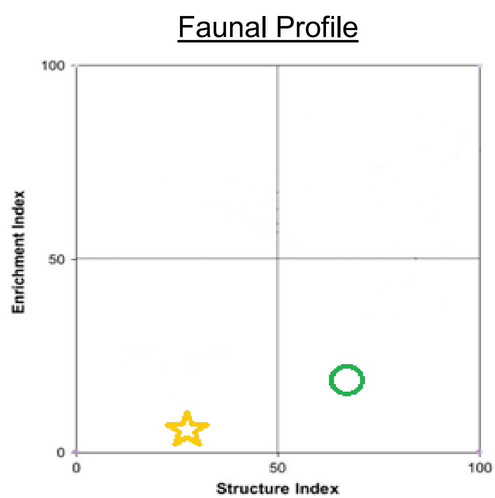

Figure 5. Nematode food web Structure and Enrichment levels in soil samples taken in Kenna Cartwright Park, Kamloops B.C. N= 79. The Structure Index (SI) and Enrichment Index (EI) values of the site occupied by invasive plants is represented as a yellow star, SI= 35, EI= 6.2. The reference site predominated by native plants is represented as a green circle, SI= 66 , EI=13.6.

Results indicate that sites occupied by invasive plants *C. stoebe* and *L. dalmatica* have less diverse nematode communities compared to the native bluebunch wheatgrass site. I observed a total of 12 different nematode genera (Figure 6).

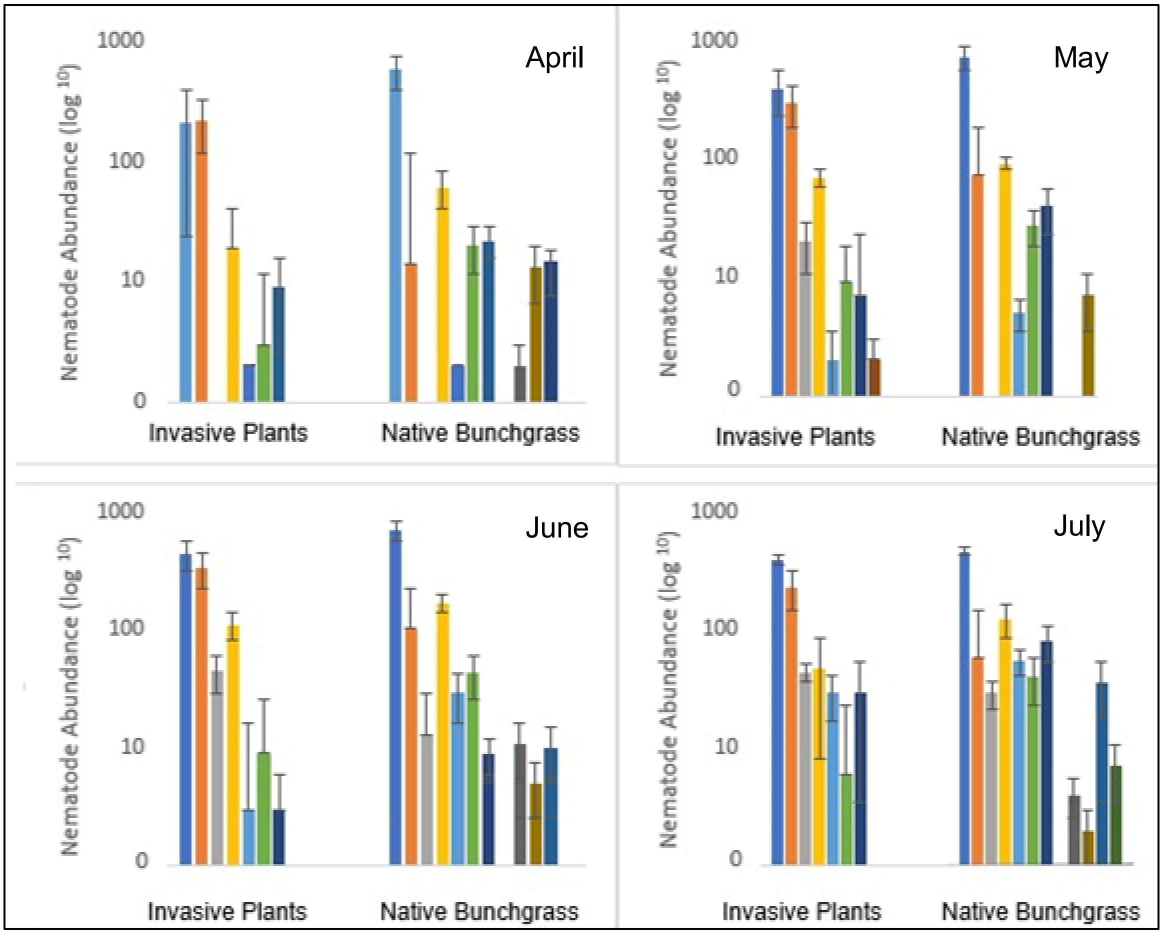

Figure 6. **Nematode abundance and diversity from soil samples extracted from April - July 2018 in Kenna Cartwright Park, Kamloops B.C. Nematode genera are displayed as follows: blue = *Tylencholaimus*, orange = *Acrobeles,* grey = *Cervidellus,* yellow = *Aphelenchus*, light blue= *Paratylenchus*, green= *Aporcelaimidae,* purple = *Chiloplacus,* red = *Rhabditis,* dark grey = *Longidoridae*, brown = *Criconematidae,* dark blue = *Dorylaimellus*, and dark green = *Pungentus.* Not all species are observed every month. Note, abundance is in (log ^{10}) scale. N=79.**

The site occupied by invasive plants had a higher PPI/MI ratio of 1.83 compared to the native bunchgrass site with a PPI/MI ratio of 1.6, indicating both sites are under nutrient poor conditions and the native bunchgrass site is slightly more Structured, or less disturbed, compared to the site occupied by invasive plants.

Table 2. The seasonal average from April - July 2018 of the Maturity Index (MI), the Plant Parasitic Index (PPI), and the PPI/MI ratio in both study sites in Kenna Cartwright Park, Kamloops. N=79

Site	MI	PPI	PPI/MI
Invasive Plants	1.625	2.825	1.825
Bunchgrass	1.875	2.9	1.6

Results of the observed seasonal abiotic soil factors show no statistical differences between the site occupied by invasive plants and the native bunchgrass site for any of the abiotic factors I measured. I conducted a Welch two sample t-test to compare the pH levels in both sites. Results were statistically significant and show little difference in the mean pH level of the native bunchgrass site (M=7.5, SD= 0.8) and the site occupied by invasive plants (M=7.6, SD=0.9); $t(79)= 2.4$, $p = 2.1e^{-14}$**.** I monitored soil pH levels between sites April - July and the seasonal pH levels are in the normal parameters of nematode suitability (Jordan et al. 2008, Andonian and Hierro 2011). Throughout the summer in both sites the difference in pH levels fluctuated in unison.

In KCP the soil temperature and soil moisture levels were similar in both sites April- July. Results were statistically significant and show little difference in the soil temperature in the native bunchgrass site (M=22°C, SD= 8.9) and the site occupied by invasive plants (M=22°C, SD=8.5); $t(79)= 22.4$, $p = 2.2\ e^{-16}$**.** The mean soil temperature in both sites April – July was 22 °C which is considered suitable soil conditions for the nematode community in a bunchgrass ecosystem (Bakonyi and Nagy 2007, Darby et al. 2011). I ran a Welch two sample t-test to compare the soil moisture (VMC) in both sites. There was a significant difference in the soil moisture in the native bunchgrass site (M=13%, SD=3.9) and the site occupied by invasive plants (M=11%, SD=3.9); $t(79) =27.0$, $p= 1.6\ e^{-6}$ **.**The mean soil VMC in both sites was 11.8% which are suitable soil moisture conditions for the nematode community in a bunchgrass ecosystem (Bakonyi and Nagy 2007, Darby et al. 2011).

Not surprisingly, the soil abiotic factors that I observed and monitored indicate strong seasonal effects on soil moisture and soil temperature in both sites. Results showed a negative correlation of soil moisture, or volumetric moisture content (VMC), with soil temperature (r^2= -0.6, n = 79 , $p = 3.59e^{-9}$). Through the summer soil moisture gradually decreased and soil temperature gradually increased.

Discussion

The goal of my study was to use nematodes as bioindicators to compare soil properties between a native bunchgrass site and a site occupied by invasive plants. My study compared soil properties including soil food web structure and soil abiotic factors between sites, and results from this study may be applied as baseline data to determine soil degradation and the soil ecosystem response to invasive plant establishment. Observing soil nematode biodiversity and applying the CP scale and appropriate indices land managers can quantify the level of soil degradation to compare sites and prioritize areas for treatment.

Land managers and restoration practioners can use nematodes as bioindicators of soil properties to manage invasive plants because Basal soil food webs are demonstrated to facilitate establishment of invasive plants, including *C. stoebe* and *L. dalmatica* (Reinhart and Calloway 2006, Jordan et al. 2008). Invasive plants can alter soil structure and soil biota to facilitate establishment (Meiman et al. 2005), and soil microbes, including nematode species, can promote or inhibit invasion. Soil food webs classified as Structured or Enriched and sites with a high PPI/MI ratio can enable bunchgrass growth (Verschoor 2002, Jordan et al. 2008, Andonian and Hierro 2011).

My results show different mean CP levels in a native bunchgrass site compared to a site occupied by invasive plants. Different CP levels indicate that soil food web structure is significantly different between sites. A key result of my study applies the Enrichment Index and Structure Index to the site CP levels to classify soil food web structure as Basal in a site occupied by invasive plants, and to classify soil food web structure as Structured in a native bunchgrass site (Figure 4). Results provide baseline data of soil properties in two sites in KCP and with continued sequential assessment of soil properties across KCP results can indicate how invasive plants affect soil properties to facilitate establishment.

The results from my study support the use of nematodes as bioindicators of soil food web structure, soil properties and functions because the results from my study are consistent with other studies that use soil nematodes as bioindicators of soil food web structure and ecosystem disturbance (Bongers 2001, Jordan et al. 2008). In my study identifying the soil nematode community and comparing soil food web structure in two different sites provided baseline data of soil properties and with continued sequential assessment can be applied to identify soil properties that may facilitate invasive plant establishment in KCP. The studies Meiman et al. (2005), Ferris (2010), and Kardol et al. (2010) also use nematodes as bioindicators of soil food web structure and from the soil food web classification can infer general soil properties and functions. Understanding soil properties of a site provides criteria that can enable land managers to determine which areas are most likely to promote invasive plant establishment (Anderson 2003, Reinhart and Calloway 2006, Mueller et al. 2018).

A less structured (or more Basal) soil food web facilitates establishment of invasive plants and enables a competitive advantage for invasive plants over bunchgrass (Reinhart and Calloway 2006, Jordan et al. 2008). Soil food web structure is related to invasive species establishment because the nematode community responds to disturbance and invasion, and changes in nematode community structure are part of the reason that certain invasive plant species gain a competitive advantage. For example, sites with higher PPN abundance may restrict growth of *P. spicata*, but sites with less PPN abundance may enable invasive plants to establish because invasive plants might be less effected by local soil biota like PPN compared to native *P. spicata*. Recognizing positive feedbacks that facilitate invasive plant establishment, like how invasive plants alter soil biota communities, and understanding concepts like the 'enemy-free hypothesis' and ecosystem resilience can enable land managers to effectively restore bunchgrass ecosystems disturbed by invasive plants.

In my study, I monitored several soil abiotic factors through the summer. Soil pH levels remained constant through the summer. Results from the two sites do not demonstrate significantly different pH levels between sites and do not indicate invasive plants alter soil pH levels to facilitate establishment. However, study recommendations include more sites to be sampled to provide a larger sample size of soil cores to analyse soil properties in a larger sample area in KCP. Other studies that use nematodes as bioindicators of soil properties show that when soil pH is slightly altered, +/- 1 pH, the pH change also influences soil nematode abundance and biodiversity (Jordan et al. 2008, Andonian and Hierro 2011), however, results in both sites showed no fluctuation beyond +/- 0.1 pH. Monitoring how the nematode community responds to changes in soil pH is one way to use soil nematodes as bioindicators of invasive plant establishment, as some invasive plants are shown to alter soil pH (Di Tomaso 2000, Jordan et al. 2008).

Another soil abiotic factor I monitored was the soil volumetric moisture content (VMC), or soil moisture. Results show a correlation of decreasing soil moisture as soil temperature increases through summer. An increase in soil temperature and a decrease in soil moisture can influence the nematode community (Bakonyi and Nagy 2007). Soil moisture is also affected by precipitation, and precipitation affects nematode abundance greatly by altering plant growth, soil nitrogen mineralization, and other soil microbial activity (Darby et al. 2011). A decrease in soil moisture is correlated to a decrease in nematode abundance because plants will produce less root mass in drier soil, in turn providing less energy sources for plant parasitic nematodes (Andonian and Hierro 2011). Also, most soil nematodes require moist soil for reproduction, feeding, and movement (Simons 1973, Bakonyi and Nagy 2007). Nematodes are less motile in dry soil compared to moist soil and cannot disperse or migrate to acquire resources (Wallace 1968).

Soil dryness and soil temperature increase is a well-documented seasonal effect in bunchgrass ecosystems (Hope et al. 1991, Anderson 2003, FAO 2014). The observed range of soil moisture and soil temperature were within the parameters of suitable conditions for the soil nematode community (Ferris 1985, Porazinska et al. 2002). Some long-term studies have observed nematode species respond to short-term climate variation and, thus, may be affected by long-term climate change (Porazinska et al. 2002, Blankinship and Niklaus 2011).

In the PPxh subzone extreme changes in soil moisture are exasperated by invasive plants (Meiman et al. 2005, Jordan et al. 2008) and changes in soil temperature and moisture are further influenced by climate change (Kardol et al. 2010, Wang et al. 2012). The results from my study show only one summer of the annual seasonal effect on soil moisture and soil temperature change, and long-term monitoring is required to determine how changes in soil moisture and soil temperature are affected due to changing climate. The soil nematode community and soil abiotic properties in KCP can be routinely monitored to determine seasonal changes in soil moisture and temperature, and the effects of climate change on the PPxh subzone.

A pilot survey with a larger sample size of soil cores extracted from a larger sample area across KCP will further determine the effect of invasive plants on soil properties and the bunchgrass ecosystem response to invasive plants. The data collected should include soil abiotic factors like moisture, temperature, and pH, as well as nematode community analysis. Soil cores should be sampled across KCP, and the larger data set will help determine how soil food web structure and other soil properties in the PPxh subzone are affected by climate change and establishment of invasive plants. Specific details of the park scale soil survey and monitoring methods are discussed further in the Recommendations section (Figure 7).

Colonizer- Persister Scale and Applied Indices

The CP scale integrates nematode trophic groups and life strategies into functional guilds to enable definition of several indices that describe structure, function and condition of the food web relative to disturbance or enrichment (Ferris 2010). Interpretation of the CP scale requires knowledge of the relationships between the nematode community and invasive plant species of interest. In my study I applied the CP scale to determine a weighted rank 1-5 of the observed nematode community, and then applied the Maturity Index and Plant Parasitic Index to further increase the resolution of the community analysis to determine soil food web structure. Plant parasitic nematodes are the focus of my study, as I analysed the nematode community to determine the effect of invasive plant establishment on soil properties and the nematode food web.

The relevance of the family or genera level assignments using the CP scale has been justified on the basis that nematodes with similar morphology and feeding habits, and similar life history traits, have a probability of similar sensitivity and responsiveness to environmental change (Bongers and Ferris 2001). During soil development and ecological succession, the general opportunists of the nematode population, or ‘Colonizer’ type species, are replenished by ‘Persister’ type nematode species. The nematode guilds representative of the food web conditions do not represent succession in the sense that one group is replaced by another group as food web complexity increases (Bongers 2001). Many nematode species and guilds use different food sources, so at each level of food web complexity all guilds are represented, and the proportions of nematode species and abundance change with alterations in food web dominance patterns (Bongers 2001, Ferris 2010).

A variety of nematode guilds were observed in the soil in both sites. Each guild indicates a level of food web structure and is ranked on a scale of 1-5 from ‘Colonizer’ to

‘Persister’. For example, carnivorous nematodes such as *Monochina* are considered sensitive to disturbances because of their systematic relation with the *Dorylaimina*, so this species is given a CP value of four (Bongers 1999). When an ecosystem is subjected to a disturbance, such as establishment of invasive plants, the CP-5 and CP-4 guilds are the most susceptible to change and abundance will decrease after a disturbance. This is followed by the CP-3 guilds, until all that may remain in a soil food web of a disturbed or degraded ecosystem are colonizer guilds CP-2 and CP-1. The CP scale established by Bongers (1990) has continually been substantiated and applied through use studying and analysing nematodes around the world (Jordan et al. 2008, Cesarz et al. 2015, Mueller et al. 2018, Griffiths et al. 2018).

‘Enriched’ food webs are described as when a disturbance occurs, and resources become available (Bongers 2001). This definition references disturbances such as fire or fertilization, but this is not the case with disturbance by invasive plants *C. stoebe* and *L. dalmatica*. Invasive plants reduce food web complexity and ecosystem resistance to further invasive establishment (Kuang 2015) and the invasive plants *C. stoebe* and *L. dalmatica* do not make resources available, they decrease available nutrients and moisture in the soil (Andonian and Hierro 2011, Vandegehuchte et al. 2015).

The Plant Parasitic Index, or PPI, is computed only for plant feeding nematodes with the rationale that their abundance is determined by the vigour of their host plants, which in turn is determined by ecosystem enrichment (Bongers and Ferris 2001, Wilson and Duarte 2009). The Maturity Index, or MI, is based on non-plant feeding taxa and considered a measure of environmental disturbance. Low MI values indicate a disturbed environment and high MI values indicate a stable environment (Bongers 1990, Bongers 1999). The PPI/ MI ratio is a sensitive indicator of enrichment in ecosystems and is lower under nutrient poor conditions and higher in enriched or stable conditions (Bongers and Ferris 2001, Griffiths et al. 2018). The mean PPI/MI ratio of the native bunchgrass site was 1.825 and the mean PPI/MI ratio of the site occupied by invasive plants was 1.6, indicating both sites are under nutrient poor conditions and the native bunchgrass site is slightly more stable, or less disturbed, compared to the site occupied by invasive plants.

I analysed the nematode community by applying both indices as a ratio PPI/MI because many of the species of interest in this study are plant parasitic nematodes. *Tylenchida,* a family of PPN, is excluded from the MI calculation because the PP/MI ratio will increase if the PPN measure is based on *Tylenchid* plant feeders only, as the *Tylenchia* family is usually more abundant than other species (Bongers 1997). The MI and PPI in both study sites were calculated, and the PPI/MI ratio provides the highest resolution of the nematode faunal profile and shows that soils in both sites have low Enrichment levels and the site predominated by native bunchgrass has more Structured soil compared to a site occupied by invasive plants (Figure 5).

Some nematodes are more responsive than others to ecosystem disturbance and resource enrichment. For example, generally bacterivores with short lifecycles and high reproductive potential most closely mirror the bloom of bacteria. Longer-lived and hardier fungivores species are indicators of fungal abundance. Plant parasitic nematodes are important contributors to food web resources because the PPN guild interacts through direct herbivory. Other guilds of nematode predators are responsive to changes in the abundance of their bacterial, fungal, or nematode prey. Therefore, a single nematode sample can provide indication of resource flow through bacterial and fungal channels and through an important herbivore channel (Bongers and Ferris 2001, Ferris 2010).

Implications for Ecological Restoration

Invasive plants can cause a variety of negative ecological and economic effects through their potential to influence ecosystem properties and corresponding ecosystem services and functions. Invasive plants alter the composition and structure of vegetation communities and often results in a change in ecosystem functions (Erskine and Rejmánek 2005, Guo et al. 2018). Several studies determined that Basal soil food webs can enable invasive plant establishment (Reinhart and Calloway 2006, Jordan et al. 2008), and Structured and Enriched soil can promote native plant growth (Ferris 2010, Mueller et al. 2018). Therefore, to restore the bunchgrass community structure in KCP requires removing and managing invasive plants to a level where invasive plants are not disrupting ecological function. However, to effectively manage ecosystems occupied by invasive plants and restore native bunchgrass ecosystem functions land managers should consider potential ecological restoration opportunities and constraints.

There are several conditions that may constrain restoration of the native bunchgrass ecosystem in KCP including technical barriers, economic barriers, and social and political barriers (FAO 2014). Technical barriers that may constrain restoration include knowledge of appropriate rehabilitation techniques, access to planting materials, and local ecological conditions like degraded soil and invasive species competition. In KCP technical constraints can be managed with continued research like Tarasoff (2002), Hindley (2018), and this study to develop knowledge of appropriate restoration techniques for invasive plant management. A survey of the plant community in KCP has not been conducted since 2001 (Figure 2) (Tarasoff 2002), but partnerships with KCP and other students in the nearby school Thompson River University or SFU and BCIT can provide opportunities to survey and map the plant composition in KCP.

Economic or financial conditions that may constrain restoration of the native bunchgrass ecosystem in KCP include the high cost associated with long-term monitoring and management of invasive plants (Di Tomaso 2000, FAO 2014, GCC 2017). Different treatment methods may have different associated costs, but in general in most bunchgrass plant communities there is opportunity to apply less expensive treatment methods like grazing or prescribed fire to restore the bunchgrass plant community and manage invasive plants. In KCP simply monitoring invasive plant growth or locating new areas of invasive plant establishment and treating areas disturbed by invasive plants is generally not a practical way to eradicate invasive plants and is not a cost-effective management method (Tarasoff 2002, Mueller et al. 2018, Pers. obs. 2018).

Applying nematodes as bioindicators in KCP, soil properties may be classified and used as criteria to identify sites to prioritize for treatment to eradicate invasive plants. Criteria that may be used to prioritize sites for treatment include distance from trail, observed invasive plant establishment, and soil properties like food web structure, enrichment levels, soil pH, and VMC. Successful eradication programs or management plans of invasive plant populations may apply management criteria, including soil properties, to cost-effectively identify and prioritize sites for treatment as demonstrated by Erskine-Ogden (2005) and discussed in Anderson (2003), and Reid et al. (2009).

For example, in two areas with no observed invasive plant establishment, a site identified with Basal food web structure and near a trail intersection might be prioritized for treatment compared to a site with a Structured food web and isolated from nearby trails. Applying multiple criteria like soil properties enables applying treatment and management practices where it is most effective, and possibly enabling pre-treating areas of high risk of invasive plant establishment. Possible treatment methods to use before invasive plants are easily observed or established include controlled burning, soil enrichment, or temporary trail closure. After a site is initially treated for invasive plants a monitoring and management phase can take place in selected sites until the bunchgrass ecosystem in KCP is fully restored.

Social conditions that may constrain restoration of the native bunchgrass ecosystem in KCP include a social resistance to prescribed burning and associated smoke, and social resistance to trail closures in KCP. Although policy in Kamloops enables prescribed fire (City of Kamloops 2013), a recent proposed prescribed burn was met with public resistance (pers obs. 2017, 2018). Social constraints like resistance to prescribed fire or trail closures can become an opportunity for public education to increase awareness and communicate the need for appropriate ecological restoration treatments and potential benefits for the public.

Managing invasive plants by restoring and maintaining native bunchgrass ecosystem biodiversity in KCP contributes to preserving the social value of bunch grasslands. In Kamloops, the activities with the highest number of participants and most frequent participation in provincial parks are hiking, and nature viewing/ appreciation (City of Kamloops 2013). A key reason the public chooses KCP for recreation is the extensive trail system that enables hikers to experience the native bunchgrass ecosystem. Additionally, the study site and suggested treatment areas are in traditional territory of First Nations group Tk’emlúps te Secwe̓pemc (TteS), the Secwepemc view all aspects of their knowledge, including language, as vitally linked to the land and place social value toward preserving and maintaining native bunchgrass ecosystems (TteS 2019).

Classifying the soil food web structure is the first step to determine soil and ecosystem response to invasive plants. Using the CP scale and appropriate indices of the soil nematode community observed in KCP, restoration practitioners or land managers can make a general diagnosis of KCP soil properties and functions and classify soil food web structure as ‘Enriched’, ‘Structured’ or ‘Basal’. My study provides data to compare nematodes as bioindicators of soil food web structure in the PPxh subzone, and baseline data to further monitor the bunchgrass ecosystem response to invasive plants.

With sufficient monitoring and data collection in KCP land managers can identify and prioritize sites for treatment based on soil properties including food web structure and ecosystem response to invasive plants. Once sites are prioritized for treatment, appropriate treatment methods may be applied in selected sites for most effective results. Future monitoring is key, as routine analysis of the nematode community enables for rapid assessment of response to disturbance or management treatments and provides criteria for effective soil enrichment and ecosystem restoration (Bongers 2002).

Management of invasive plants must use a variety of treatments to be effective, as each invasive plant species may require different treatment methods. Treatment methods may include hand pulling certain invasive plants such as *L. dalmatica* (Di Tomaso 2000, Jacobs 2006, Hindley 2018) or supporting a fire disturbance regime to promote bluebunch wheatgrass growth and limit spread of *C. stoebe* (Patton et al. 1988, Guo et al. 2018). To manage invasive plants, and the PPxh ecosystem, restoration practitioners may apply soil biota as tool to indicate soil properties and ecosystem functions of a bunchgrass ecosystem and the ecosystem response to disturbance of invasive plants.

The implications of my results influence our understanding of the ecology of bunchgrass ecosystems by providing a CP scale and MI/PPI ratio of the soil nematode communities in KCP and the PPxh subzone. The results of the soil nematode community can be applied as baseline data of how soil food webs and other soil properties are altered by invasive plants in KCP. The data presented in my study is relevant to nematology, as a specific ecosystem type has been surveyed and the nematode community indexed. Data of the nematode community abundance and biodiversity can be applied in nematology studies in other bunchgrass ecosystems to further understand species distributions and ecosystem functions like nutrient cycling or carbon storage (Bongers and Ferris 2001, Wilson and Duarte 2009, Yeates 2010).

Managing and treating KCP for invasive plants will increase native plant abundance and biodiversity, in turn improving grazing for wild ungulates like bighorn sheep and mule deer because bluebunch wheatgrass is nutritional forage and cover (Hope et al. 1991, GCC 2017) and invasive plants are toxic for many species (ISC 2014). Other ecological effects of promoting growth and establishment of native *P. spicata* is additional cover and denning sites provided for species at risk like sage grouse (*Centrocercus phaios)* or rubber boa (*Charina bottae)* (Krannitz and Rohner 1999, SARA 2018). Bluebunch wheatgrass grasslands contribute to many ecosystem functions, like reducing soil erosion, carbon storage, nutrient cycling, and improving soil and water quality (Sheley and Krueger-Mangold 2003, Carlier et al. 2009). Bunch grasslands also provide food and range for domestic livestock, and if managed appropriately can provide sustainable economic benefit (GCC 2017). The bluebunch wheatgrass ecosystem in KCP provides key ecosystem functions but is less functional while disturbed by invasive plants.

The results from my study may be used to manage invasive plants in bunch grasslands used for recreation, agriculture, or grazing for livestock. Bunch grasslands were historically used as land for agriculture and rangeland for livestock and can be sustainably managed today (GCC 2017). To monitor the many ecosystem functions of bunch grasslands, like water filtration and erosion control, nematode community composition can be monitored and used as bioindicators of changes in soil food web structure or nutrient cycling and decomposition channels (Bakonyi and Nagy 2007, Blankinship and Niklaus 2011). With further monitoring and data collection the results from my study might be widely applicable to bunch grasslands in the PPxh subzone for a variety of management purposes. The opportunities and constraints of restoring a bunchgrass ecosystem disturbed by invasive plants can be managed to restore ecosystem functions (Jacobs and Sheley 2003, D'Antonio and Chambers 2013).

Nematode Extraction

I designed a sampling plan for estimating nematode abundance and species composition based on several practical and theoretical considerations. The design of the sampling plan considered the required accuracy of identification, the time frame, as well as the costs involved. I also included knowledge about the variation in space and time of nematode populations, their biology, and the influence of abiotic factors. All these factors must be considered to arrive at a correct application of timing and depth of sampling, tools to use, and number of samples to take and sampling pattern.

Choosing the correct extraction method is crucial depending on the question the experiment is asking, and what nematode species are of interest. Extraction efficiency improved greatly when I pre-extracted the soil sample using sieves to filter the soil before the centrifugal flotation technique. A source of variance in the centrifugal extraction method is the chance of washing out a very small nematode species that may pass through the sieve, but the probability is low, and the variance does not influence the study significantly (Van Bezooijen 2006).

Sampling limitations

A sampling limitation faced with using nematodes to indicate soil properties and functions in areas disturbed by invasive plants is to account for past decades of soil disturbance in KCP and the PPxh subzone. Previous cultivation and grazing may have greatly reduced higher trophic level nematodes, and thereby reducing their functional significance in retaining nutrients, sequestering carbon, and suppressing pest populations (Reinhart and Calloway 2006). Even in “reference” site conditions, the nematode community is likely altered by previous disturbances like overgrazing and climate change. However, nematodes can still be analysed to determine soil properties and ecosystem functions if above ground-below ground linkages are understood (Kardol and Wardle 2010).

To apply my results using nematodes as bioindicators it is necessary to cautiously interpret the causality of correlations between invasive plant establishment and ecosystem properties. One can consider potentially confounding factors of which developed first: differences in invasive plant establishment, or differences in other ecological factors, like soil properties or nematode community composition, that facilitated invasion but could be misinterpreted as “impacts” of invasion (Mueller et al. 2018). Correlations of nematode diversity and abundance to soil properties and functions can be interpreted more confidently if data is collected long-term and from a larger sample size across KCP.

I collected enough samples to provide baseline data of the soil nematode community populations to compare two sites in the PPxh BEC subzone. I monitored the two 1-ha sites to provide a basis of soil food web structure of a native bunchgrass ecosystem and of a bunchgrass ecosystem occupied by invasive plants. The data is useful to establish a baseline to design a pilot survey using nematodes as bioindicators of soil properties, including food web structure, across the extent of KCP. Soil nematodes as bioindicators can be applied to a landscape scale like the PPxh subzone as discussed in (Jackson et al. 2011, Song et al. 2017). With further annual monitoring the soil nematode community population data collected in this study can be applied on a landscape scale in the extent of KCP.

Large scale distribution patterns of soil nematodes are driven primarily by latitude, climate, and vegetation type (Song et. al. 2017). Aspect and elevation don't play as much a role in nematode species presence compared to soil pH, soil moisture, soil type, and above ground vegetation. Throughout the 800-ha area of KCP elevation and aspects vary greatly around Mt. Dufferin, however temperature and precipitation remain uniform, as well as the predominate vegetation community, apart from areas occupied by invasive plants.

Plant parasitic indices, like PPI, have no significant relationship with latitude because these indices are primarily influenced by the presence of above ground plants. Across extreme variation in latitude vegetation types will change, such as comparing temperate coniferous forests to arid grasslands. In my study the results drawn from the samples taken in the native bunchgrass site and the site occupied by invasive plants are not immediately applicable to the whole park. However, a soil survey is provided to further develop the results from my study by sampling throughout KCP using the baseline data collected and the nematode interpretation key. With robust data land managers in KCP can apply nematodes as bioindicators of soil food web structure, ecosystem functions, and ecosystem response to invasive plant establishment in the entire park and PPxh subzone.

Clearly, it was not practical nor feasible to sample the entire KCP soil nematode population in my study. I sampled a representative population of the nematode community to make inferences about the overall nematode population in the two study sites to use nematodes as bioindicators of soil properties. A larger sample size, in a larger study area, is necessary to determine the effect size of differences in the soil nematode community and soil properties in the extent of KCP.

The abiotic factors I monitored through the summer may not be representative of all KCP. Nematodes as bioindicators are applicable on a landscape scale, as discussed by (Jackson et al. 2011) and in general, the nematode community will not vary in the PPxh subzone but may be influenced by seasonal variation in moisture and temperature levels (Bakonyi and Nagy 2007). To further apply the data I collected of the soil nematode community biodiversity, it is necessary to monitor and extract soil samples in KCP annually for at least 3 years. Due to seasonal effects on the soil, plant biodiversity, and nematode biodiversity, further sampling is to continue in the summer from April to August.

Long-term monitoring will ensure soil nematodes are not influenced by localized seasonal soil abiotic effects and that the nematodes will come out of anabiosis, a state of extreme dormancy to survive harsh conditions (Treonis and Wall 2005). Monitoring the nematode community abundance and diversity for at least three years will improve the sample size and create more robust data. Although the results of my study show that CP levels are statistically significantly different between sites, additional data collection and monitoring through the summer is required to confirm that results are both statistically significant and biologically significant in the extent of KCP.

Recommendations

Monitoring and Research

This study provides baseline data and a snapshot of the soil food web structure and ecosystem properties of the sites surveyed. Each study site is to continue to be sampled and monitored four times throughout the summer, once per month from April to July, annually for the next 3-5 years. In addition to monitoring the nematode community present in the soil core samples, data of basic soil abiotic factors such as soil moisture (VMC), soil pH, and soil temperature are to be monitored through the summer. The study sites are also to be monitored for any disturbance, such as animal grazing, fire, or human use, like creation of a new trail.

These data are more robust if trends in nematode population biodiversity and abiotic soil factors are monitored over time. Considering the strong seasonal effect on abiotic factors such as changes in precipitation and temperature, the nematode community composition should ideally be monitored for 3-5 years to monitor a range of seasonal conditions. After a minimum of 3 years nematode populations are anticipated to stabilize and come out of anabiosis (Treonis and Wall 2005). Also, long-term plant-soil feedbacks have been shown to influence soil biota years after plant establishment (Kulmatiski and Beard 2010), so sites should be monitored after initial treatment. If each site is monitored each summer for 5 years, the native bunchgrass site and the site occupied by invasive plants will be monitored until 2023 and sites in the pilot survey throughout KCP will be monitored until 2024.

It is difficult to obtain long-term data on the response of ecosystems to treatments because monitoring programs are often planned for short time periods, but involving researchers in the implementation and monitoring of treatments can enable long-term monitoring necessary to determine treatment effects (Di Tomaso 2000, Heneghan et al. 2008). Maintaining a long-term partnership between the City of Kamloops nature parks and the SFU/BCIT Master of Science in Ecological Restoration program can be mutually beneficial to managers and researchers. Fostering these relationships can advance our understanding of the long-term effects of treatments.

With the completion of my project, land managers in KCP may use nematode analysis to rank areas in the park by food web structure and soil properties, and with continued monitoring and data collection, apply nematodes as bioindicators to rank sites by response to invasive plant establishment. Areas predominated by ‘Colonizer’ nematode species and Basal soil can enable invasive species establishment compared to sites predominated by ‘Persister’ nematode species and Structured soil (Reinhart and Calloway 2006, Jordan et al. 2008). Nematode biodiversity and other soil biota can be applied as indicators of invasive plant establishment as discussed by (Meiman et al. 2005, Heneghan et al. 2008). Applying criteria like food web structure and other soil properties enables land managers in Kenna Cartwright Park to efficiently prioritize sites for appropriate restoration treatments.

Each site is to be continually evaluated and sampled each year in Spring/Summer from April to July. If a disturbance like a prescribed burn occurs, it is important to document and continue monitoring the nematode population before and after the burn to record the nematode community response to fire. Incorporating a prescribed burn plan is a key part of restoring the ecosystem in KCP and to manage invasive plants, as well as increasing *P. spicata* growth and bunchgrass ecosystem functions (Hope et al. 1991, Rice 2005).

Based on the high fuel load and history of fire suppression in KCP, one recommendation is to use the data provided by this study and the suggested soil survey to influence the locations chosen for prescribed burning. Including occurrence of invasive plants, among other factors like soil moisture levels or distance from a trail, in a burn plan for KCP can influence the recommended burn intensity in specific locations. For example, a low intensity smouldering fire would likely be prescribed in a native bunchgrass site with a low fuel load, compared to a higher intensity burn would likely be prescribed in areas predominated with invasive plants to destroy the seed bank (Raison 1979, Rice 2005).

Ecological Restoration

Invasive plants should be eradicated or managed on a landscape scale to fully restore the native bunchgrass ecosystem in KCP. Considering the constraints and opportunities determined, invasive plant establishment can be managed to restore the bunchgrass ecosystem in KCP. First, a large-scale soil survey can take place to increase the study sample area across KCP and to compare and asses soil properties in the park. The survey will take 80-100 soil cores to use soil nematodes as bioindicators to identify soil properties as a criterion to prioritize areas for treatment. Areas that are sampled in the proposed survey can be prioritized for restoration treatment based on criteria like distance from trail, predominate vegetation, level of invasive plant disturbance, and soil properties like food web structure, soil enrichment, soil moisture, and soil pH.

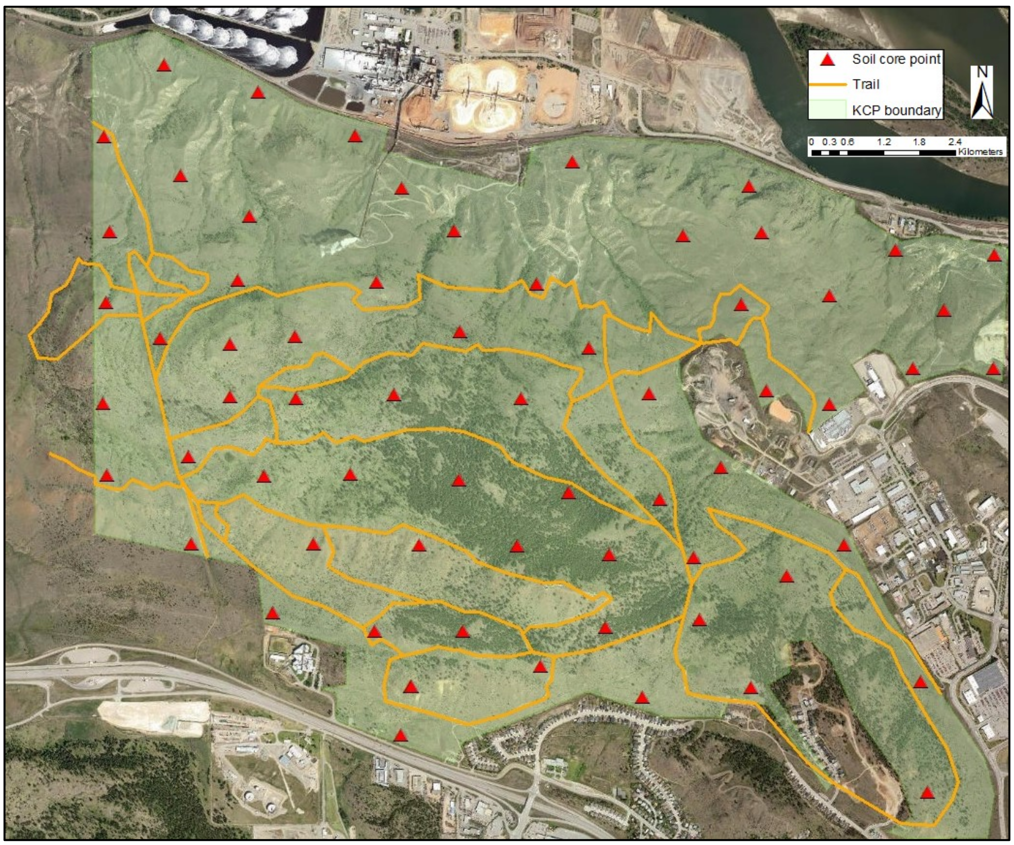

Figure 7. Map of the proposed soil survey in Kenna Cartwright Park, Kamloops B.C. The boundary of Kenna Cartwright Park is shown in green, the network of trails is shown in orange, and shown in red are 80 suggested soil sampling locations to use nematodes as bioindicators of soil properties.

After the park soil survey, soil nematodes can be extracted from the soil samples using the centrifugal flotation method. Once the observed nematode genera are identified and categorized using the CP scale, the nematode community can be applied to appropriate indices to determine the soil food web structure and soil properties of each sampling location. Soil food web structure can be analysed and compared with other sites across KCP and used to classify soil as Basal, Structured, or Enriched.

Multiple management objectives and treatments have previously been implemented in KCP. For example, to reduce the predominance of invasive plants, mainly *C. stoebe* and *L. dalmatica*, some treatments have been implemented in KCP including grazing, prescribed burning, release of biological control agents, herbicide application, and mechanical treatments. Despite implementing multiple treatments, land managers often have limited resources for monitoring, but the use of multiple treatments can create an opportunity for active adaptive management. Active adaptive management is based on the principle that no one model can correctly predict the response of an ecosystem to treatments, so management decisions should explore alternative models to gain reliable knowledge about the short-term and long-term response of a system to different treatments (D’Antonio and Chambers 2013).

Treatments for Invasive Plants

Once sites are prioritized and selected for treatment for invasive plants the appropriate site-specific treatment methods may be applied. Generally, sites with Basal soil are prioritized for treatment before Structured or Enriched soils. However other site-specific factors should be considered, including distance from trail, predominate vegetation, and level of invasive plant disturbance, i.e. stem density. Site-specific treatments will have to be determined in-situ, however general treatment recommendations for sites predominated by *C. stoebe* include low intensity grazing by goats (Dostalek and Frantik 2008, Murphy 2017), low intensity prescribed burning (Rice 2005), and hand pulling (Hill et al. 2006, D’Antonio and Chambers 2013, Hindley 2018). Similarly, treatment recommendations for sites predominated by *L. dalmatica* in KCP will be site-specific, however, the general treatment methods for *L. dalmatica* include low intensity grazing by goats and hand pulling in combination with herbicide application (Jacobs 2006, Guo et al. 2018, Hindley 2018).

Conventional treatments for invasive plant control and management include physical, chemical, and biological practices (Guo et al. 2018). Physical and chemical treatments may lead to unintended, usually negative consequences, unless carefully planned and implemented. For example, physical removal like hand pulling will rarely completely eradicate the invasive plant community and can cause disturbance that can facilitate further invasion (Heneghan et al. 2008). Chemical treatments and biological control agents are limited because the treatments can harm other species through unanticipated side effects (Erskine and Rejmánek 2005, Jacobs 2006, Guo et al. 2018). Therefore, an approach that might be more practical and low risk is the “ecological approach” (Guo et al. 2018) which emphasizes the restoration of native species by biomass manipulation, like selective grazing or prescribed burning and seeding with native species.

Grazing

Grazing using goats is a growing practice of ecological restoration (Cummings et al. 2016, Murphy 2017, Guo et al. 2018) and is an effective treatment for managing invasive plants *C. stoebe* and *L. dalmatica* because goats will graze the invasive plants once they are trained to eat it and have been used to reduce weed biomass and seed production (Cummings et al. 2016, Murphy 2017). Consecutive years of grazing or mechanical removal can deplete the residual seed bank (Jacobs 2006, Cummings et al. 2016). However, to prevent spread of invasive plant seeds through their faeces, grazing animals that may have consumed these seeds should be contained and fed weed-free seed and forage for five days before being moved to weed-free areas (Jacobs 2006). Grazing with goats after herbicide application can be used to reduce *L. dalmatica* regeneration and potentially increase the time between herbicide re-applications (Jacobs 2006).

Goats can be managed by herders to avoid grazing native plants and goats cause minimal compaction in comparison to machines and humans (Murphy 2017). Goat grazing reduces seed production, but the long-term effects of goat grazing at reducing populations are under-studied. Goat grazing has been used as part of the invasive plant management program in KCP. Goats were used over a four-year period starting in 2012 and ending in 2015. However, considering the longevity of seeds of both *C. stoebe* and *L. dalmatica*, four years of grazing without other treatment methods would be insufficient to deplete the seed bank.

Prescribed Fire

Prescribed burning can be an effective treatment method to manage *C. stoebe* because low intensity smouldering fire can remove *C. stoebe* plant biomass and eradicate the seedbank (Rice 2005). Unlike treatment recommendations for *C. stoebe*, prescribed fire is not recommended to control and eradicate *L. dalmatica* (Jacobs and Sheley 2003) because fire can facilitate reducing biomass of other plant species, like *P. spicata* or *C. stoebe*, but the extensive root system and deep seed bank of *L. dalmatica* enable the plant to recover quickly after fire and predominate the landscape (Rice 2005, Jacobs 2006). Applied alone fire is ineffective at controlling *L. dalmatica* growth and spread but may improve the effectiveness of herbicidal, biological, and grazing control when used in an integrated management program (Jacobs 2006).

Prescribed burning provides a natural treatment option for species such as *C. stoebe* as an alternative to herbicide application, but the effectiveness of prescribed burning depends on the timing of prescribed burning, the site conditions, and the life history of plants (Rice 2005, D'Antonio and Chambers 2013, ISC 2014). The effect of prescribed burning differs between the two invasive plants *C. stoebe* and *L. dalmatica*. Prescribed burning might reduce the population of *C. stoebe* if site conditions are conducive low intensity smouldering fire. Prescribed burning in the early spring is likely beneficial for native bunchgrass *P. spicata* and to reduce the biomass of *C. stoebe*. Future prescribed burns should incorporate alternative treatments for *L. dalmatica* such as herbicide application.

Herbicide

Herbicide use is a common tool for the eradication of invasive plants, including *C. stoebe* and *L. dalmatica*. In B.C., the use of herbicides is regulated under the *Integrated Pest Management Act* (Province of British Columbia 2003). To effectively manage the invasive plants *C. stoebe* and *L. dalmatica* herbicidal control requires high application rates and repeated applications applied at bloom in May or June or to fall re-growth (Jacobs 2006, Mac Donald et al. 2013). The thick waxy leaf cuticle, long-lived seeds, and creeping root system are biological characteristics that present a challenge for effective herbicidal management of *L. dalmatica* (Jacobs 2006). Herbicide application has resulted in short-term reduction of *L. dalmatica* and *C. stoebe* populations in similar bunchgrass ecosystems (Jacobs 2006) but results of herbicide trials on *L. dalmatica* have been variable with very good control in some applications to nearly no control in other applications of the same treatment in KCP (Tarasoff 2002, Hindley 2018) and other experiments in bunchgrass ecosystems (Jacobs 2006, Mac Donald et al. 2013).

Also, herbicide application can affect native plants that are not the target for eradication. The most common method of herbicide application is broadcast spraying, which can result in effective short-term reduction of invasive plant density (Jacobs 2006, Mac Donald et al. 2013) but can result in spraying other plants with herbicide that are not the target species for management. Over multiple herbicide treatment applications, changes of abundance of native plants can alter species interactions and change community composition, and result in possible negative effects to wildlife, by reducing soil microbial diversity and altering soil chemistry (Mac Donald et al. 2013).

Biological Control Agents

Biological control agents, or biocontrol agents, are used for invasive plant management based on the hypothesis that stress on an invasive plant by a natural enemy will be enough to reduce competitive ability of invasive plants, ultimately reducing the population size (Hezewijk et al. 2010). Biocontrol agents are selected based on host-specificity, but often the effects of biocontrol agents on non-target native species are poorly studied prior to release, and the use of biocontrol agents is controversial because the methods involves releasing a non-native predatory species to target other non-native species (Heneghan et al. 2008, Hezewijk et al 2010). In B.C., 13 biocontrol agents have been identified for *C. stoebe*, and seven biocontrol agents have been identified for *L. dalmatica* (Ministry of Forests, Lands and Natural Resource Operations 2018).

Biocontrol agents, mainly *Mecinus janthinus,* a stem mining beetle, have been released in KCP in 1988 for *C. stoebe* and 1994 for *L. dalmatica* (Tarasoff 2002). Results from the biological control release in KCP show a decline in density (stems/ m^2) of *L. dalmatica* after 7 years of application of *M. janthinus* (Tarasoff 2002). *M. janthinus* is capable of dispersing and colonizing areas up to 25 km from release locations within 13 years of release (Hezewijk et al. 2010), so it is expected to occur in all sites in KCP.

Hand Pulling

The effect of hand-pulling is similar between both invasive plants, but because of the life history of *C. stoebe*, hand-pulling is likely more effective at removing *C. stoebe* compared to *L. dalmatica* (Di Tomaso 2000, Hindley 2018). Hand-pulling over consecutive years can deplete the seed bank of *C. stoebe*, however, *L. dalmatica* can germinate after hand-pulling and can still be capable of producing seeds (Jacobs 2006, Hindley 2018). Hand-pulling is only recommended for small communities of invasive plants or in combination with other treatments because of the high labour cost.

Seeding

Other treatments for managing *C. stoebe* in a bunchgrass ecosystem that can be effective are seeding with native grasses and trail closure to prevent further spread of invasive plants (Miller 2013). Native seed mix of *P. spicata* can be purchased from local plant nurseries, and seeding is most effective to promote growth of *P. spicata* in early spring or after prescribed fire. Hand seeding is effective in small sites, but to efficiently seed a landscape like KCP one should consider methods like hydro-seeding or aerial seeding with a helicopter.

Applying treatment combinations can be effective if the effects of the treatment combinations are adequately understood (Kuang 2015). For example, hand-pulling is a mechanical treatment that is labour intensive but highly specific to target plants, while managing invasive plants with prescribed fire is less labour intensive and operates on the assumption that restoring natural processes to the ecosystem will eradicate some invasive plants and enable native species to recuperate. The longevity of invasive plant control in KCP and the PPxh subzone will depend on site soil conditions, the intensity of competition from other plant species, and grazing and fire management. Biomass management of invasive plants using prescribed burning, grazing, and harvesting can result in relatively stable ecological conditions and can more effectively limit the spread and establishment of invasive plants (Guo et al. 2018).

Abiotic soil properties, like soil pH, soil temperature, and soil moisture can be measured while extracting soil cores as demonstrated in my study. Soil characteristics can be determined by using nematodes as bioindicators so land managers can identify areas with low soil enrichment, and consequently enrich the degraded soil of the site. Some potential treatments to enrich degraded soil in KCP include low intensity prescribed fire, or spreading mulch created by chipping the fallen ponderosa pine trees in KCP. Both recommended treatment methods use the plant material on site to enrich the soil and reduce the high fuel load in KCP.

Factoring other Ecosystem Stressors

The viability of the native bunchgrass ecosystem in KCP is affected by ecosystem stressors that are beyond the scope of this study. Fire suppression is an underlying issue that needs to be addressed in KCP. As discussed, a prescribed burn in appropriate areas in an acceptable time frame and under suitable conditions like favourable winds would limit the effects of smoke on the public. In the PPhx subzone and the bunchgrass ecosystem in KCP fire can reduce invasive plant establishment and promote growth of bluebunch wheatgrass *P. spicata* (Rice 2005).

Another ecosystem stressor in KCP that can be addressed is seed dispersal and erosion caused by public recreation. Depending on results of the park soil survey and monitoring observations, potential recommendations could include trail closures in areas of high use with presence of invasive plants. Lastly, climate change must be factored into almost every ecological restoration project. In KCP and the PPxh subzone land managers are preparing for more extreme drying events and more high intensity fires (Volenec and Belovsky 2018). Altered climate conditions in the PPxh subzone may facilitate further establishment of invasive plants (Andonian and Hierro 2011, GCC 2017). Because of the strong influences from neighboring areas (i.e., as potential invasive species source), local restoration and management efforts in the future should consider the regional context and projected climate changes.

Summary and Conclusions

As restoration practitioners, the ability to assess soil properties to provide criteria to prioritize sites for invasive species treatment is a useful tool for managing ecosystems affected by invasive plants. Managing for invasive plants is a growing challenge in ecological restoration and understanding above-ground and below-ground linkages is necessary to select treatments that will eradicate or negatively affect invasive plant population growth. Some options to analyse the ecosystem response to invasive plant establishment, like monitoring available nutrient content or soil structure, may be restrictive to data collection due to the high cost of lab analysis. Nematodes as bioindicators can determine soil food web structure, and soil properties and functions, so land managers can quickly analyse the bunchgrass ecosystem response to invasive plant establishment at a low cost by applying the CP scale and appropriate indices.

A biodiverse and abundant soil nematode community is a long-term restoration goal as Structured and Enriched soil food webs and sites with a high PPI/MI ratio can enable bunchgrass growth (Verschoor 2002, Jordan et al. 2008, Andonian and Hierro 2011). Continued monitoring of the soil nematode community in KCP using the recommended soil survey will enable land managers to assess and compare soil properties across the park and manage for invasive plants on a landscape scale (Jackson et al. 2011).

The City of Kamloops and KCP have objectives to limit the spread of invasive plants, in turn restoring the native bunchgrass ecosystem and key ecosystem functions that support a variety of wildlife and human services (City of Kamloops 2013). The CP scale and nematode interpretation key provided by this study, with applied indices, can determine site soil food web structure and soil properties and where appropriate ecological restoration treatments can be applied in KCP for most effective results.

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Appendix

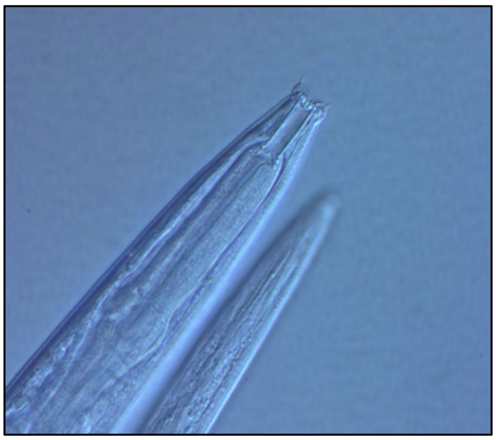
Site Photos

Figure A1. High fuel loads of a) dead and fallen ponderosa pine and b) predominance of invasive plants in Kenna Cartwright park in June 2018.

Figure A2. Invasive plants *C. stoebe* and *L. dalmatica* observed in Kenna Cartwright Park in June 2018.

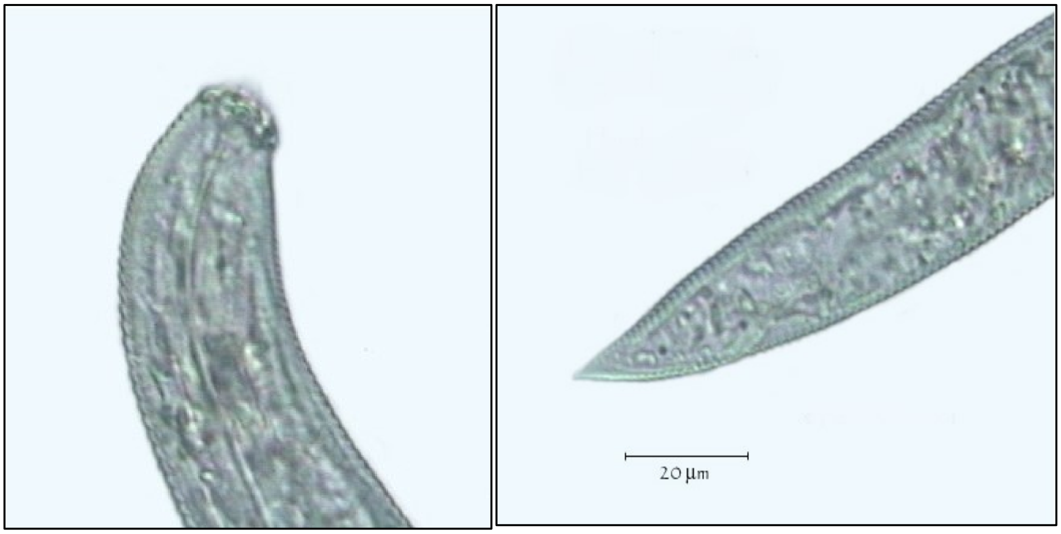
Nematode Interpretation Key

I observed the following 12 genera of soil nematodes in KCP April - July. Some genera were only observed in sites occupied by invasive plants, and other nematode genera were only observed in sites predominated by bluebunch wheatgrass (*P. spicata).* This identification key uses photos I took of nematodes extracted from samples taken from KCP, and the identification key uses photos from *Nemaplex,* an open source identification key created by H. Ferris to enable easier identification of nematodes. All photos are at 400x resolution unless otherwise indicated.



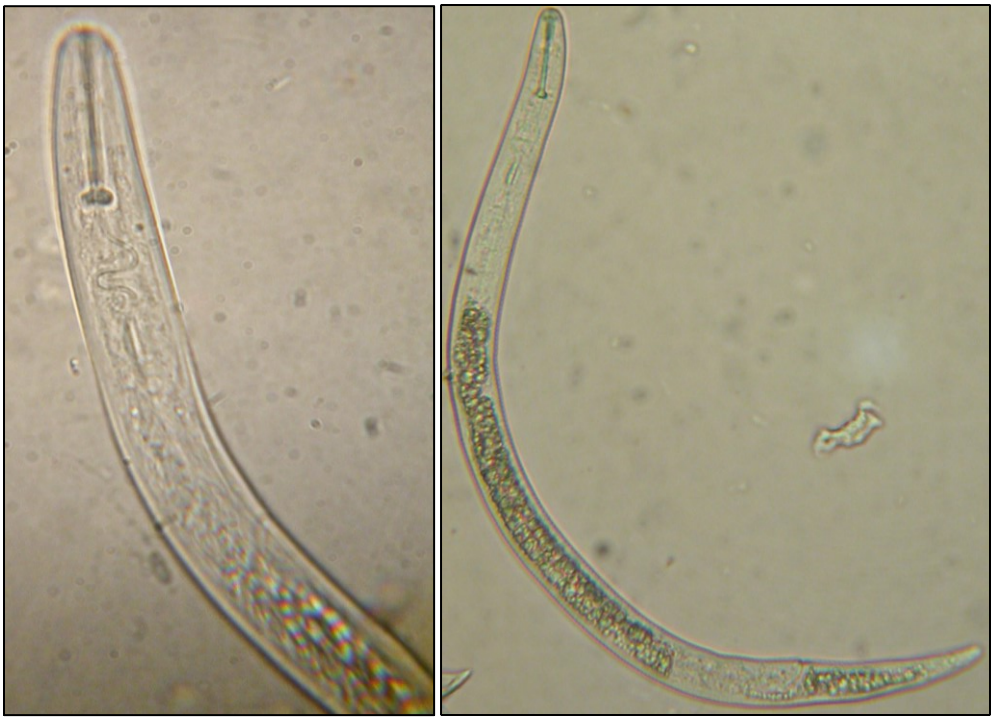

***Rhabditis spp*. Morphological features that enable identification of this genera include no stylet, mouth cavity wide and tubular, tail without spinneret, mouth cavity walls parallel. Feed on bacteria and decomposing plant matter, CP rank is 1, observed in sites occupied by invasive plants and not observed in sites predominated by native bluebunch wheatgrass (P. spicata). Photos by Nemaplex.**


***Acrobeles spp*. Morphological features that enable identification of this genera include no stylet, mouth cavity closed, lip ornaments concpicuous, forked and fringed. A bacterial feeding nematode, persists in disturbed soil conditions, CP rank is 2, observed in both study sites. Photos by O. Denny.**

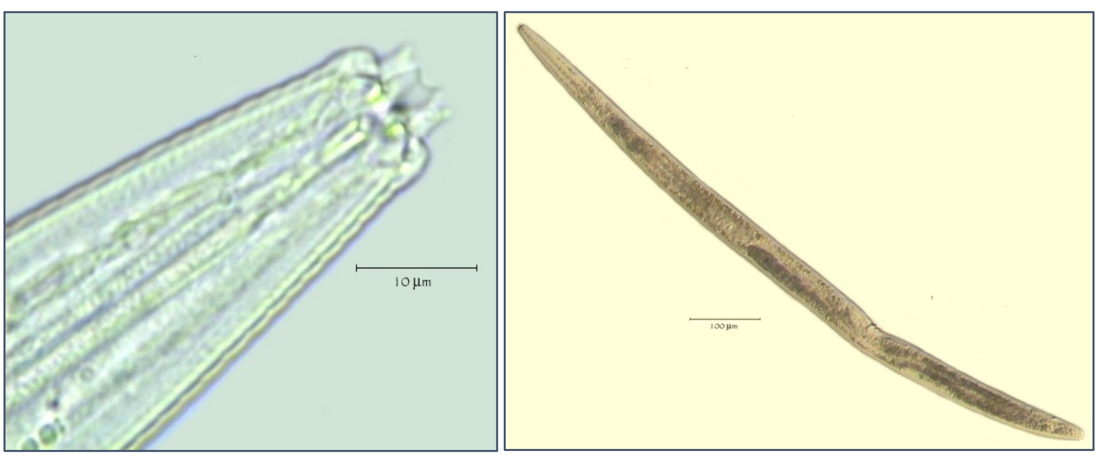


Cervidellus spp. **Morphological features that enable identification of this genera include no stylet, mouth cavity closed, lip ornaments finely forked or Y shaped, not fringed. Small body less than 0.5 mm long. Feeds on bacteria, CP rank is 2. Photos by Nemaplex.**

Aphelenchus spp. **Morphological features that enable identification of this genera include a stylet with no knobs, median bulb and valvular apparatus. Tail is bluntly rounded, body almost straight. Genearlly a fungal feeder, CP rank is 2. Photos by Nemaplex, second photo 40x resolution.**

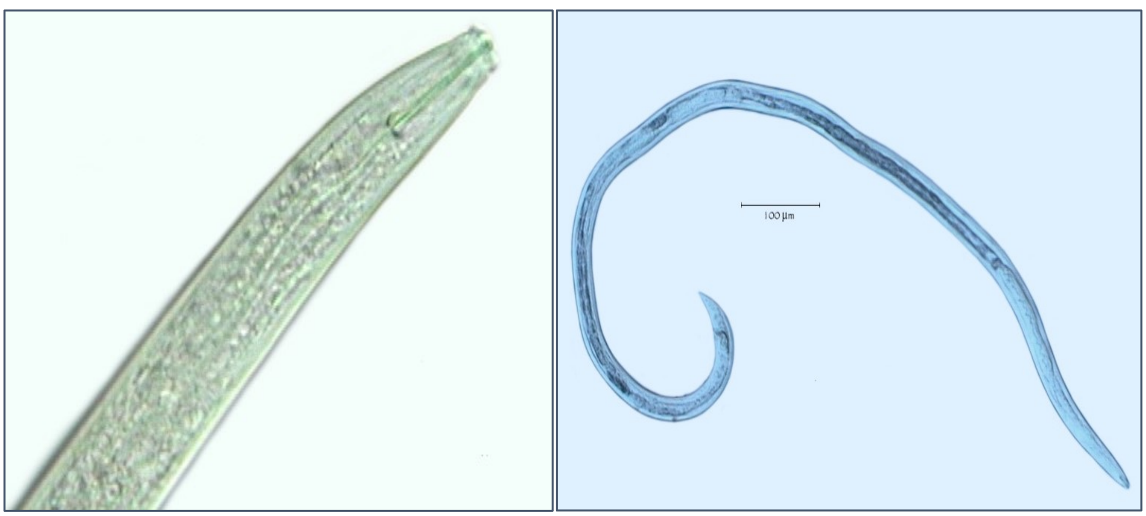


***Paratylenchus spp*. Morphological features that enable identification of this genera include a stylet, median bulb, and valvular apparatus. The stylet is short and strongly developed, tail blunt, lip region flattened, body is small less than 0.5 mm long, becomes C shaped when killed by heat/ dryness. Plant parasitic, CP rank is 2. Photos by O. Denny.**

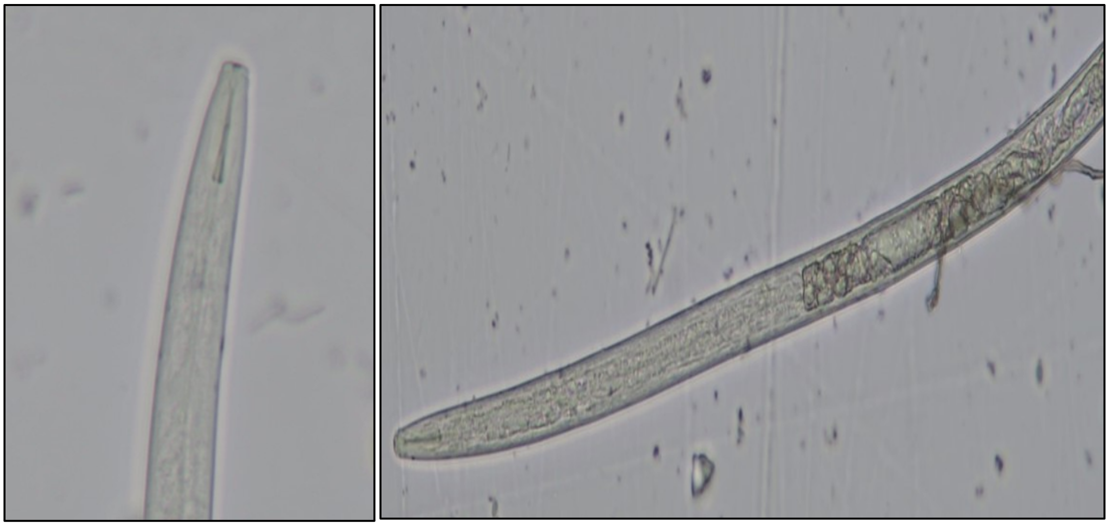


***Chiloplacus spp.* Morphological features that enable identification of this genera include no stylet, mouth cavity closed, several lips, tail acute, and small body less than 0.5 mm long. Baceterial feeder, CP rank is 2. Photo by O. Denny, second photo by Nemaplex, 40x resoultion.**

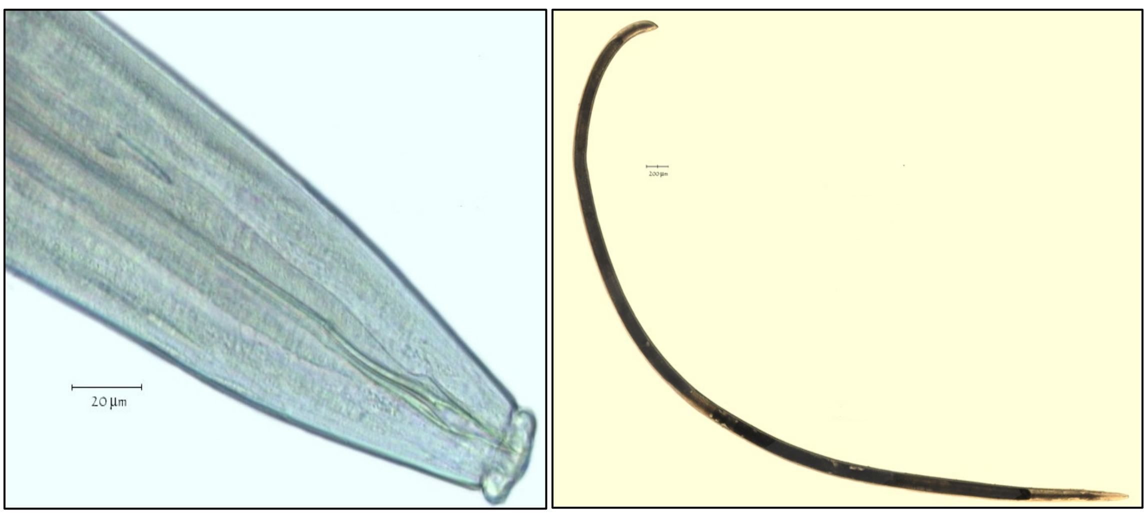
***Criconematidae spp*. Morphological features that enable identification of this genera include stylet, median bulb, and valvular apparatus. Oesophageal glands do not overlapping, one gonad, and body with broad annules, little and plump. Ectoparasitic on plant roots, CP rank is 3. Photos by Nemaplex, first photo of head is at 1000x resolution.**



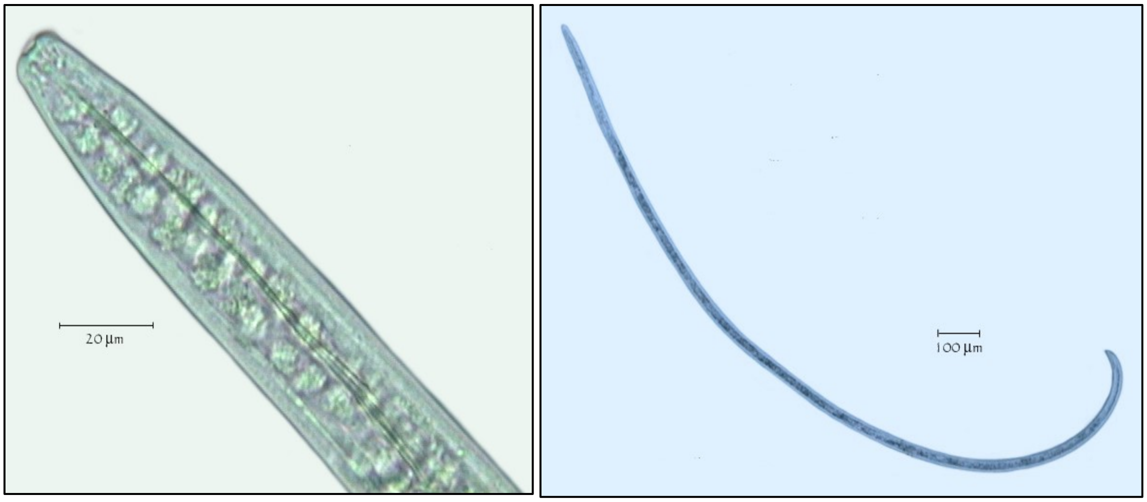
***Dorylaimellus spp.* Morphological features that enable identification of this genera include a stylet, median bulb, and valvular apparatus. Oesophagal glands do not overlap, two gonads, body has longitudinal grooves. Lip region is narrow. Plant and hyphael feeders, CP rank is 3. Photo by O. Denny, second photo by Nemaplex, 40x resolution.**



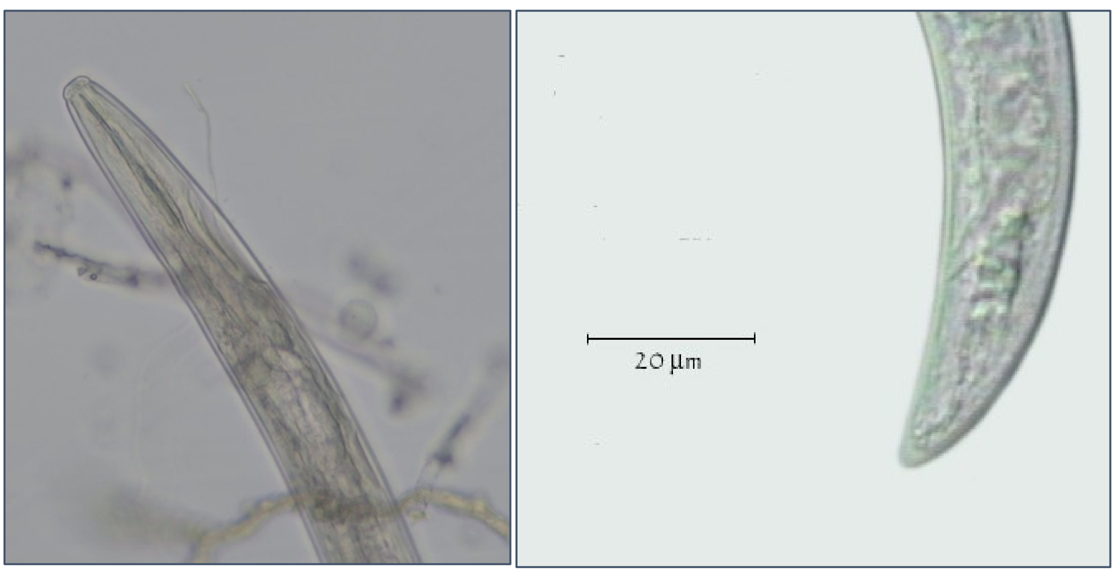
Tylencholaimus spp. **Morphological features that enable identification of this genera include a stylet, without a median bulb, the stylet structure is complex and has extension with knobs, lip region cap like. Plant parasitic nematode abundant in both study sites, CP rank is 5. Photos by O. Denny.**



Aporcelaimidae spp. **Morphological features that enable identification of this genera include a stylet, without a median bulb, the broadened oesophageal part is not surrounded by a muscle sheath, the stylet is a short spear with a large aperture, tail cuticle obviously two layered. Body is larger than most species, 1.5- 10 mm long. Nematode predacious, CP rank is 5. Photos by Nemaplex, second body photo at 40x resolution.**



***Longidoridae spp*. Morphological features that enable identification of this genera include a long stylet, without a median bulb. The broadened oesophageal part is not surrounded by a muscle sheath, body is very long (3-12 mm), extremely slender. CP rank is 5. Photos by Nemaplex, second photo of body at 40X resolution.**



***Pungentus spp.* Morphological features that enable identification of this genera include a stylet, without a median bulb, the broadened oesophagal part is not surrounded by a muscle sheath, the body is straight, blunt tail, stylet is curved, and light refraccting particle around oral aperture. Omnivore and predacious, CP rank is 5. Photo of head by O. Denny, tail photo by Nemaplex.**